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ULTRAVIOLET DISINFECTION OF ACTIVATED SLUDGE EFFLUENT DISCHARGING TO SHELLFISH WATERS

J. A. Roeber, et al

Saint Michaels

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A tertiary treatment plant and an ultraviolet disinfection chamber were installed following an activated sludge plant at the municipal sewage treatment plant in St. Michaels, Maryland. The multiple-tube fermentation technique was used to determine the total coliform MPN Index after varying exposures to ultraviolet radiation. Batch tests were sampled at various intervals under constant radiation and flow-through tests were sampled before and after undergoing radiation. The standard to be met was an MPN of not more than 70 per 100 ml. In flow-through tests this was usually achieved with a flow not in excess of 40,000 gallons per day, with a turbidity of less than 11 JTU, using sixteen germicidal 36 watt ultraviolet lamps, an energy application of .035 KWH/1000 gallons. The absorption of ultraviolet radiation, as measured by the absorption coefficient, was much more dependent on COD than on turbidity, indicating the appearance of the effluent is not the best criterion for estimating the rate of U.V. treatment unit. Both Coliforms and Bacteriophage multiplied when exposed to visible light after ultraviolet radiation treatment. Coliform inactivation followed first order kinetics until 99.99% inactivation occurred; followed by a tailing-off curve. Bacteriophage followed first order kinetics up to the maximum available ultraviolet rate.

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ULTRAVIOLET DISINFECTION OF ACTIVATED SLUDGE EFFLUENT DISCHARGING TO SHELLFISH WATERS

by

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for

THE TOWN OF ST. MICHAELS
ST. MICHAELS, MARYLAND 21663

Project No. WPRD 139-01-68

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MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This report describes a unique disinfection process applied to a municipal wastewater effluent to protect a shellfish area.

ABSTRACT

A tertiary treatment plant and an ultraviolet disinfection chamber were installed following an activated sludge plant at the municipal sewage treatment plant in St. Michaels, Maryland.

The multiple-tube fermentation technique was used to determine the total coliform MPN Index after varying exposures to ultraviolet radiation. Batch tests were sampled at various intervals under constant radiation, and flow-through tests were sampled before and after undergoing radiation.

The standard to be met was an MPN of not more than 70 per 100 ml. In flow-through tests this was usually achieved with a flow not in excess of 40,000 gallons per day, with a turbidity of less than 11 JTU, using sixteen germicidal 36 watt ultraviolet lamps; an energy application of 0.35 KWH/1000 gallons.

The absorption of ultraviolet radiation, as measured by the absorption coefficient, was much more dependent on COD than on turbidity, indicating the appearance of the effluent is not the best criterion for estimating the rate of U.V. absorption, or the initial intensity required to penetrate to the bottom of the U.V. treatment unit.

Both Coliforms and Bacteriophage multiplied when exposed to visible light after ultraviolet radiation treatment.

Coliform inactivation followed first order kinetics until 99.99% inactivation occurred; followed by a tailing-off curve. Bacteriophage followed first order kinetics up to the maximum available ultraviolet rate.

This report by Clow Corporation for City of St. Michaels, Maryland, was submitted in fulfillment of Project Number WPRD 139-01-68 under the partial sponsorship of the Wastewater Research Division, Municipal Environmental Research Laboratory (formerly the Advanced Waste Treatment Research Laboratory, National Environmental Research Center), U.S. Environmental Protection Agency. Work was completed December 21, 1972.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
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FROM: Gilbert M. Gigliotti G.M.G./J.B.
Director, Technical Information Staff

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National Technical Information Service
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Enclosed are 10 copies of "Ultraviolet Disinfection of Activated Sludge Effluent Discharging to Shellfish Waters" by J. A. Roeber and F. M. Hoot (EPA-600/2-75-060) for inclusion in the National Technical Information Service. All required information and forms are included.

If you have any questions or need any other information, please call Mrs. Thomasine Bayless (513-684-7282). Thank you for your cooperation.

Enclosures

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The administrative, technical, professional, fiscal and legal details of the project were handled by the Clow Corporation Waste Treatment Division.

The original project director was Emerson E. Longrell of St. Michaels; however, his untimely death occurred 2 weeks after the start of the project.

The original Assistant Project Director was E. F. Bradley of Clow Corporation. He resigned 2 months after startup.

John A. Roeber, of Clow Corporation was the Project Engineer during the entire project. He also served as Acting Project Director.

Mrs. Helen Plummer of St. Michaels was the Project Finance Officer.

Frank Hoot was the Resident Engineer.

The support of the project by the Environmental Protection Agency and the help provided by Harold Snyder, Richard Brenner and Cecil W. Chambers, the Grant Project Officer is acknowledged with sincere thanks.

SECTION I

CONCLUSIONS

1. The ultra-violet disinfection process should be used following well-controlled activated sludge plants. Ultraviolet disinfection of effluents containing high solids and high organics was not possible at the U-V exposure levels available.

2. In static (batch) tests, the average ultraviolet dose in microwatt seconds per square centimeter to produce an effluent with a coliform MPN Index less than 70 was about 25,000, with an exposure time of 120 seconds.

3. In dynamic (flow-through) tests with 130 seconds exposure, the coliform MPN was usually below 70 when the turbidity was below 11 JTU and above 70 with higher turbidity.

4. The absorption of U-V, and therefore, the initial intensity needed to penetrate the flow-through cell, was much more dependent on the COD of the influent than on the turbidity. A continuous process should be controlled by both an organic detector and a turbidity meter.

5. Samples initially higher in coliforms, when subjected to the same ultra-violet dosage had higher numbers of surviving coliforms than did samples with lower initial coliforms.

6. Exposure of samples to visible light after a sublethal dose of ultraviolet exposure favors the continued multiplication of bacteria, while a decline in density was noted in a sample kept in the dark.

7. Bacteriophage inactivation by ultra-violet radiation followed first order kinetics.

8. Bacteriophage subjected to a sub-lethal dose of ultraviolet radiation and then exposed to visible light continued to multiply.

9. Sixteen (16) 36-watt ultraviolet germicidal lamps were shown to reduce the coliform MPN of a good activated sludge effluent to below 70 at a flow rate of 40,000 gpd, at an energy consumption of .35 Kilowatt hours per thousand gallons.

SECTION II

RECOMMENDATIONS

This project was very limited in funds for virus determinations, so that by the time a modest program was outlined the activated sludge plant was no longer producing an acceptable effluent. It is recommended that the viricidal capability of ultraviolet radiation be compared with chlorination.

Further work should be done with an activated sludge plant that produces a consistently good effluent to determine the day-to-day bactericidal efficiency of ultra-violet radiation. This project was limited to 10 coliform determinations twice a week by space, equipment, and manpower.

The amount of ultra-violet should be increased an order of magnitude to determine if photoreactivation can be overcome. Higher wattage U-V sources should be used so the flow velocity is sufficient to prevent solids deposition. The ability of a stronger U-V source to handle programmed plant upsets or the inevitable accidental ones should be investigated. The energy requirement of this project was relatively modest at 0.35 KWH/1000 gallons, so that higher U-V doses would be practical. Higher strength ultraviolet lamps are available, but their efficiency in converting electrical energy to ultraviolet energy is low. The demonstration that ultraviolet radiation of effluents is practical could possibly hasten the development of a high wattage high efficiency ultraviolet source. This would bring down the electrical operating cost as well as the capital cost as the result of smaller structural requirements.

SECTION III

INTRODUCTION

The effluent from every waste treatment plant which has been constructed in shellfish areas up to the present time has adversely affected shellfish, and the receiving waters in the vicinity of effluent lines have all been restricted to the harvesting of shellfish. The size of the restriction has depended on many factors; such as, effectiveness of plant operation, degree of treatment provided, size of plant and reliability of the treatment process. The effluent from a well-operated activated sludge treatment plant discharging 100,000 gallons per day can be responsible for the restriction of hundreds of acres of surface water.

Public Health Service Bulletin #1500 entitled "National Register of Shellfish Areas"[1] shows that approximately 2,000,000 acres of shellfish growing water out of a total of 10,000,000 acres are presently closed to the harvesting of shellfish. By far, the greatest portion of this is due to the effects of effluents from waste treatment plants.

The grant was approved May 10, 1968. The equipment installation was completed and the plant startup was on Nov. 26, 1968. Operation continued to the end of the original 18-month period plus a six-month and a two-month extension.

The community of St. Michaels, Maryland, which had an existing activated sludge plant, was directly concerned over the loss of shellfish harvesting, value of riparian real estate, and the effect on tourist business. They applied for and received an EPA Research Grant (WPRD-139-01-68) for 75% of the cost of installing and operating for 18 months a "Controlled Treatment System" manufactured by Yeomans Division of Clow Corporation. 12½% of the funds were supplied by Clow Corporation and 12½% by the State of Maryland. The Controlled Treatment System is based on U. S. Patent #3,459,303.

Five factors important in the plant design, which is to be applied to an activated sludge plant effluent are:

(1) The effluent must have a very low bacterial count; i.e., not greater than an MPN of 70 coliforms per 100 ml.

(2) There should be a significant reduction in the number of viruses below that which is now found in a plant effluent.

(3) The effluent must contain no harmful chemicals.

(4) There must be no by-passing of raw or partially treated wastes to the receiving waters.

(5) All of the above criteria must be maintained continuously if the receiving waters are to be opened to the harvesting of shellfish.

Effluent from the activated sludge plant is given a tertiary chemical treatment if necessary and then flows under ultra-violet lights through 3-inch deep troughs. The amount of U-V is measured at the bottom of the trough. If the U. V. is below a preset point which is known to give satisfactory disinfection, the effluent is automatically discharged to a holding lagoon instead of to the shellfish receiving water. The malfunction is corrected, and the lagoon-stored effluent is then pumped back through the plant for adequate treatment. Continuous indicating and recording flow meters, ultra-violet meters and turbidity meters are used. Either high turbidity or low U-V will signal the operator at the same time the improperly treated effluent is automatically bypassed to the holding lagoon.

All chemical and bacteriological testing was done at the sewage treatment plant site in a house trailer fitted as a laboratory. Ultraviolet radiation was used as a means of disinfection and the determination of the coliform MPN was the primary evaluation test.

The bactericidal, viricidal and fungicidal properties of ultraviolet (U-V) radiation are well known. The germicidal U-V lamp is a low pressure mercury lamp designed so that more than half of the input energy is generated by the mercury vapor at its predominant wavelength of 2537 Angstroms (A^o), as the bactericidal effect peaks between 2500 and 2700 A^o.

In most disinfection processes, the rate of kill is expressed by

$$\frac{dn}{dt} = -KN$$

where $\frac{dn}{dt}$ = rate of kill

K = rate constant

N = number of living micro-organisms

N_o = number of living organisms at time zero

If $\text{Log } \frac{N}{N_o}$ is plotted against time, a straight line should be obtained with a slope K which is proportional to radiation intensity.

The intensity of radiation is reduced as it passes through an absorbing medium. It is recommended the depth of liquid in the irradiation chamber should be such that not more than 90% of the U-V should be absorbed by the time the UV reaches the bottom of the chamber.

The reduction in intensity is expressed by

$$I = I_o e - Kd$$

where I = radiation intensity

I_o = initial radiation intensity

e = base of natural logarithms

K = absorption coefficient

d = distance between points where the intensities are I_0 and I

The average intensity thru the chamber is

$$Iave = I_0 \quad \left(\frac{1-e^{-Kd}}{Kd}\right)$$

The U. S. Public Health Service policy statement of April 1, 1966 on the "Use of Ultraviolet Process for Disinfection of Water" was used as a guide in sizing the disinfection chamber. See Appendix A.

The Controlled Treatment system was designed to process a good activated sludge effluent. Changes were made until June, 1969 to improve the operation of the activated sludge to produce a good quality secondary effluent, i.e. about 20 mg/l BOD instead of the 150 mg/l average that was produced thru April, 1969.

SECTION IV

ACTIVATED SLUDGE PLANT

The ultraviolet disinfection experiments were conducted on the effluent from an existing activated sludge plant in the town of St. Michaels, Maryland on the Miles River.

The activated sludge plant receives the domestic sewage from about 1500 persons in the town. Sewage is pumped to the plant from two pumping stations located at terminal points in the sewage collection system. Both pumping stations discharge to a common force main which terminates at the sewage plant.

The sewage plant was constructed in 1953 to treat 100,000 gallons of sewage per day. Due to infiltration and population growth, daily flow varied greatly and the plant was hydraulically overloaded. During the period from June 1969 to May 9, 1970, when these experiments were carried out the lowest daily flow recorded was 85,000 gallons and the highest daily flow was estimated at 383,000 gallons. The average daily flow during this period was 143,000 gallons.

Due to the variation in flow and recirculation of sewage to the primary settling tank, detention time in the 16,950 gallon tank varied. Settled material from the primary settling tank is mechanically scraped to hoppers and then pumped to an unheated anaerobic digestor. The settled effluent from the primary tank was split to flow three ways.

The tertiary treatment unit was operated on a pilot plant basis. Only part of the sewage biologically treated in the secondary plant was pumped to the tertiary treatment unit. A flow diagram showing the relation of the secondary plant and the tertiary unit with the division of flow is shown in Figure 1.

During the course of the experiments, the secondary treatment plant was operated on a split treatment basis. Implementation of the split treatment process was necessary due to the hydraulic overload on the plant and the deteriorated condition of the secondary settling tank. These conditions prevented production of a good quality effluent. The split treatment process enabled the production on part of the sewage of a secondary effluent that was consistent with effluent that could be produced from a satisfactory operating activated sludge plant.

Part of the primary effluent was diverted to a combined aerator-clarifier unit. Aeration is provided in the outer perimeter of the tank with a circular secondary settling tank in the center of the tank. Flow to the unit was controlled by an orifice installed in the primary tank effluent trough. The orifice was adjusted to pass 105,000 gallons of sewage per day. Capacity of the aeration part of the tank is 49,700 gallons. Aeration originally was accomplished by a surface aerator which spilled sewage over a fixed plate on top of the secondary clarifier. The rated capacity of the surface aerator would "turn over" the sewage in the aerator every ten minutes. The draft tube from

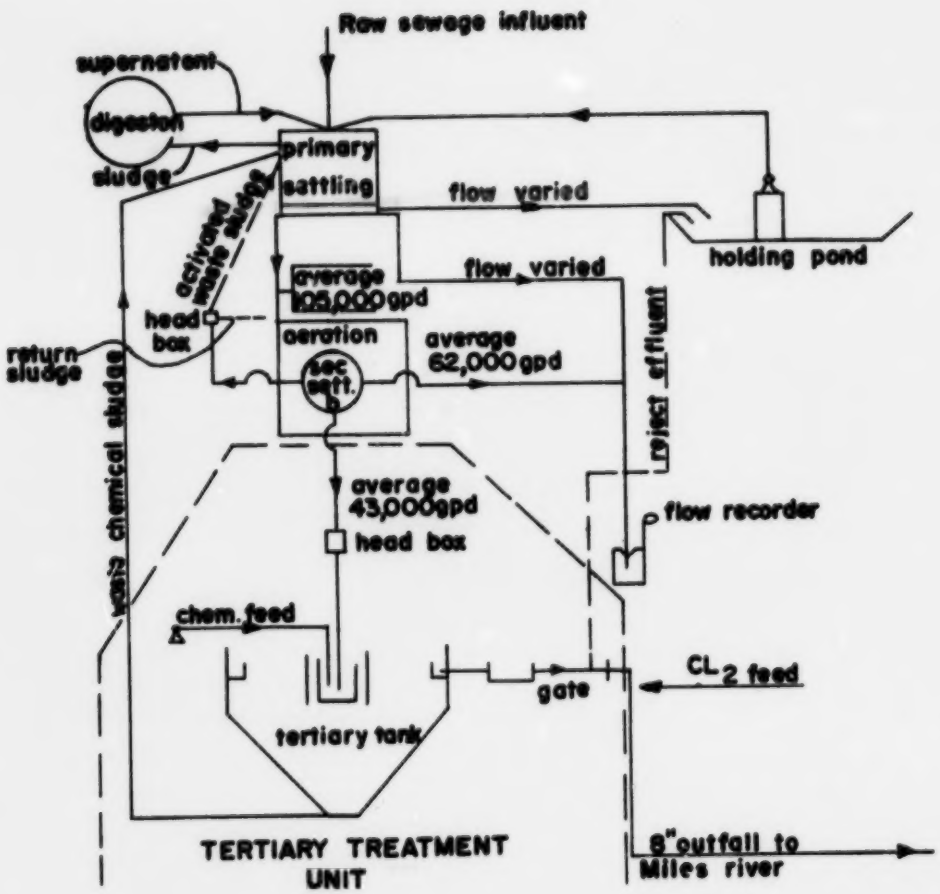

FIG. 1

FLOW DIAGRAM OF SPLIT TREATMENT PROCESS
AND TERTIARY PLANT

which the surface aerator drew sewage from the bottom of the tank ran through the clarifier. The outer shell of the clarifier tank was badly pitted and corroded. With the high turnover rate this caused currents in the secondary clarifier and resulted in poor secondary settling.

To overcome this condition, a new blower was installed and the aeration tank was fitted with bottom air diffusers. Six air lines were put down into the tank, each with a horizontal arm equipped with 18 air diffusers. This arrangement provided good aeartion and did not upset the secondary clarifier. At the 105,000 gallon per day flow rate, the mixed liquor solids could be maintained at about 1200 - 1400 mg/l with a minimum dissolved oxygen content in the mixed liquor of 1.5 - 2.0 mg/l.

After aeration, the sewage flowed into the 16 foot diameter central clarifier unit. The upper part of the unit is a cylindrical tank with a capacity of 8,130 gallons and provided for secondary settling of the aerated sewage. The bottom of the unit is an inverted cone providing sludge settling space with a capacity of 780 cubic feet. The apex of the cone is at the bottom of the tank. An airlift pump drawing at the bottom of the apex was installed and provided for the return of the settled sludge to a head box. In the head box the settled sludge could be returned to the sewage coming into the aerator or wasted to the primary tank as needed.

Settled effluent from the clarifier was taken off on a five foot diameter weir and discharged into a trough on the outside of the aerator tank. In the trough, a flowmeter measured and recorded the flow over a 45^{o} triangular notch weir.

The final effluent was carried off by an eight inch outfall line which ran approximately 1,200 feet to a submerged discharge in the Miles River. Chlorine was injected in the 8" line with contact time provided in the pipe.

The second part of the primary effluent was diverted to a 100,000 gallon capacity holding pond on the sewage plant site. The holding pond was equipped with a time controlled pump which recirculated sewage to the influent of the primary tank. The sewage diverted to the holding pond was pumped back to the primary tank at night and during periods of low flow. By this means a fairly steady flow was maintained in the primary tank and resulted in a steady flow of sewage to the aerator.

That part of the primary effluent which was not diverted to the aerator or the holding pond was discharged to the trough on the outside of the aerator. In the trough the by-passed primary effluent was blended with the effluent from the aerator-clarifier, chlorinated and discharged to the river.

In the original operation of the plant, the flow from the primary tank was not split. All sewage was biologically treated in the aerator-clarifier unit. Due to the hydraulic overload and condition of the secondary clarifier, a poor quality effluent was produced, as determined by the five day BOD test. To evaluate the effects of the split treatment process to the normal operation, a comparison was made on calculated pounds of BOD_5 in the effluent produced by the two treatment processes. The comparison was based on total flow and average BOD_5 determinations made during periods when the two processes were in operation. The split treatment process was operated in conjunction with the tertiary unit and about 43,000 gallons of sewage received additional treatment. The effect of the additional treatment was figured in the split treatment process. This comparison is shown in Tables 1 & 2.

For the period when all sewage was biologically treated in the aeration tank the calculated average pounds of BOD_5 in the plant effluent was 185.

For the split treatment comparison period the calculated daily average pounds of BOD_5 was 66. Based on this comparison the split treatment process removed 64% more of the BOD_5 than did the normal plant operation under overloaded conditions.

After chlorination, no sampling point was accessible either for full treatment or split treatment; therefore, the actual BOD entering the receiving water could be expected to be less than before chlorination for both treatment modes; however, this BOD was not measured.

TABLE 1

COMPARISON OF SEWAGE TREATMENT PROCESSES
(Flow and BOD_5 for Comparison Periods)

NORMAL TREATMENT

Period	Monthly Flow Gallons	Average BOD_5 mg/l Before Chlorination Cl_2 Raw	Primary Sewage	Secondary Effluent	Tertiary Effluent
February 1969	3,633,000	-	-	158 (1)	- (2)
March 1969	4,899,000	183	197	143 (1)	- (2)
April 1969	4,227,000	184	207	167 (1)	- (2)
SPLIT TREATMENT					
June 1969 (15 days)	2,069,000	254	206	22 (3)	17(4)
July 1969	4,102,000	265	209	19 (3)	12(4)

(1) Total flow given secondary treatment
(2) Tertiary plant could not be operated
(3) 105,000 GPD received biological treatment
(4) 43,000 GPD treated in tertiary unit

TABLE 2

POUNDS OF BOD_5 IN EFFLUENT BEFORE CHLORINATION

NORMAL TREATMENT

Period			Pounds BOD_5 per month
February 1969	3.633 x 8.34 x 158	=	4787
March 1969	4.899 x 8.34 x 143	=	5843
April 1969	4.222 x 8.34 x 167	=	5880

Daily average pounds BOD_5 in plant effluent = 185

SPLIT TREATMENT

June 1969 (15 days)

Total Flow	2,069,000		
Secondary Effluent (15 x 62,000)	930,000	.93 x 8.34 x 22 =	171
Tertiary Effluent (15 x 43,000)	645,000	.645 x 8.34 x 17 =	91
Primary Effluent	494,000	.494 x 8.34 x206 =	849
Total Pounds BOD_5 in Combined Plant Effluent			1111

July 1969

Total Flow	4,102,600		
Secondary Effluent (31 x 62,000)	1,922,000	1.922 x 8.34 x 19 =	305
Tertiary Effluent (31 x 43,000)	1,333,000	1.333 x 8.34 x 12 =	133
Primary Effluent	847,600	.8476 x 8.34 x209 =	1477
Total Pounds BOD_5 in Combined Plant Effluent			1915

Daily Average Pounds BOD_5 in Plant Effluent = 66

SECTION V

TERTIARY TREATMENT UNIT

The tertiary unit consisted of a settling tank, an ultraviolet disinfection chamber, and controls to monitor certain parameters of the effluent. The unit was manufactured as an advanced wastewater control system. The unit was intended for use in areas where it was desirable to have continuous control and monitoring of the bacteriological quality of the discharged effluent. The bacteriological quality was to be gauged by the measure of turbidity and ultraviolet absorption in the effluent. A description of the process as designed is described elsewhere. [2]

The tertiary treatment unit was operated on a pilot plant basis in that of the 105,000 gallons of sewage per day biologically treated in the secondary plant, approximately 43,000 gallons per day were pumped to the unit. A pump was installed with the section in the secondary clarifier and discharged to a head box. The sewage flow in the head box could be adjusted, permitting regulation of flow to the tertiary unit. The unit was operated on a 24-hour basis.

Discharge from the head box was directed to a 265 gallon capacity chemical mix tank in the center of the tertiary settling unit. Calculation of flow in the tertiary unit was based on the time to fill the chemical mix tank. A chemical feed pump with discharge in the chemical mix tank was available to feed settling aids as needed. Settling aids were mixed in the chemical mix tank by a variable speed paddle mixer.

The overflow from the chemical mix tank was directed downward by a cylindrical shell around the tank. The settled effluent was drawn upward and off the tank by surface weirs located on each side of the tank. The vertical settling tank was constructed in the shape of an inverted pyramid and had a capacity of 4,760 gallons. The bottom of the tank was fitted with a sludge drawoff line.

Dye tests indicated that the average detention time in the tertiary tank was about 70% of theoretical detention time. At a flow rate of 36.7 gpm an average detention time of 130 minutes was indicated; however, by dye test, the average detention time was 92 minutes.

Settled sewage from the tertiary settling tank was directed to the ultraviolet disinfection chamber.

Sewage flowing in the disinfection chamber was subjected to ultraviolet irradiation from lamps mounted over the surface of the sewage. The chamber was fitted with meters to monitor the ultraviolet intensity after passing through a layer of the sewage, current to the ultraviolet lamps and the turbidity of the sewage. A sketch of the chamber is shown in Figure 2.

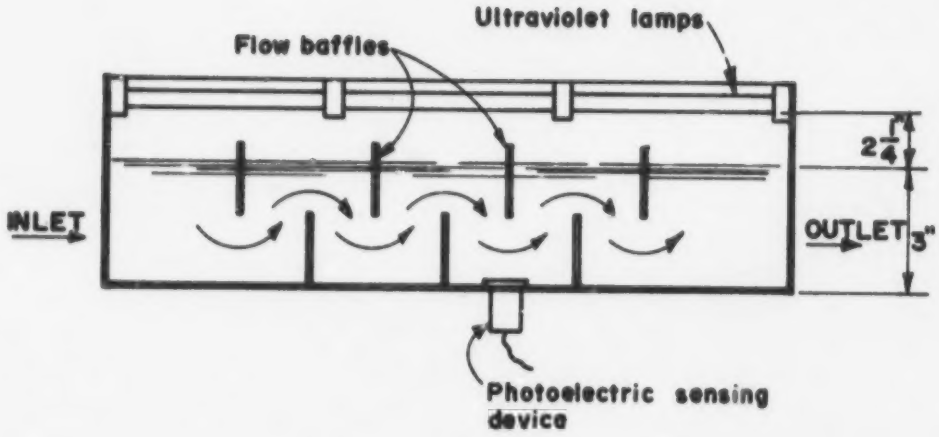

FIG. 2

DISINFECTION CHAMBER

The ultraviolet chamber was 12'-6" long by 2'-8" wide with a liquid depth of slightly less than three inches. The chamber was divided into four parallel rectangular channels which directed the flow the length of the chamber. In each chamber, baffles 1½" high were placed on fifteen inch centers. The channels and weirs were painted with aluminum paint.

Liquid capacity of the chamber is 60.8 gallons. Liquid depth in the chamber was maintained by an overflow trough at the effluent end.

Four hinged hoods covered the chamber and were arranged end to end. Each hood was fitted with a parabolic Alzak reflector and four G36T-6 36" long ultraviolet germicidal lamps. The lamps were nominally rated at 36 watts with an average ultraviolet output at 2537 A^{O} of 10.4 watts through the life of the lamp. Under normal conditions the lamp life is approximately 7500 hours. The ultraviolet lamps were arranged with the length of the tube parallel to the sewage flow. With the hoods down, the lamps were over the center of the four channels. The center of each lamp was 2-5/8" above the liquid surface.

At the effluent end of the chamber in the bottom center of each channel a quartz window was fitted. Beneath each quartz window a photo sensor was installed. The photo sensor measured the residual ultraviolet intensity with readout in microamperes on a photometer located in a control panel outside the chamber. The meter was equipped with a low level indicator. Readings below a predetermined value carried a signal to be sent to a relay in the control panel. A recorder provided a continuous record of ultraviolet intensity.

One channel was equipped with a quartz window extended under the liquid surface, enabling ultraviolet intensity readings to be made at this location. The distance between the extended window and the low quartz window was 2.81 inches. With provision to read the ultraviolet intensity at two levels in the liquid the ultraviolet absorption in the sewage could be determined.

At the effluent end of the disinfection chamber, a continuous sample of the irradiated effluent was piped to a continuous reading and recording surface scatter turbidimeter. The turbidity meter was equipped with a high level alarm, which when the turbidity exceeded a predetermined value sent a signal to a relay in the control panel.

Low level indications from the ultraviolet meter and/or high turbidity signals transmitted to the control panel served to operate a solenoid operated gate. If de-energized, the gate was dropped and diverted the effluent to the holding pond. Sewage diverted to the holding pond was recirculated to the primary clarifier, during periods of low flow.

Sewage was discharged from the unit if it had been subjected to a predetermined minimum ultraviolet exposure and if the turbidity level in the sewage did not exceed a predetermined value. The effluent from the pilot tertiary unit was mixed with the chlorinated blend of primary and secondary effluent, and the total mixture was discharged to the Miles River.

A current meter installed in the ultraviolet lamp circuit indicated the number of lamps burning. Each lamp drew about 0.5 amperes, and with 16 lamps in operation the meter read 9.0. A drop in the meter indicated the number of lamps not drawing current and diverted the effluent to the holding pond. This meter only indicated if a lamp was drawing current and did not give information on ultraviolet output. The lamps were periodically checked with the photo sensor to determine if they were producing 2537 A^{o} Angstrom ultraviolet. Operating instructions for the instrument and safety control relay box are attached as Appendix B.

SECTION VI

CONDUCT OF TESTS

Experiments with the ultraviolet irradiation of sewage effluent were conducted under static batch conditions and under actual flow-through conditions of operation in the ultraviolet disinfection chamber. The conditions of exposure in the static tests were made to approximate the conditions of exposure in the chamber.

The static tests were conducted with a sample of sewage in a rectangular pan under one of the hoods. The 36" long pan was placed in one of the troughs. The pan was fitted with a center divider and 1½" high baffles.

The pan held about 10 liters at a depth of three inches. An electrically driven paddle circulated the sewage around in the pan. Exposure time to ultraviolet radiation was controlled by the switch to the ultraviolet lamp circuit. Samples of the irradiated sewage could be withdrawn at appropriate time intervals.

Dynamic tests were made under actual flow and exposure conditions in the ultraviolet disinfection chamber. Exposure time of the sewage could be accomplished in two ways. The flow in the tertiary unit could be varied, thus varying the exposure time, or the number of lamps could be reduced. The lamps under the hoods could be removed to reduce the exposure time by one quarter, one half, or three quarters as desired.

Irradiated samples that were checked for light reactivation were put in clean, sterile, saran-covered pans and thus exposed to the natural light. Samples checked for dark exposure were similarly treated, but covered and sealed under a dark box.

All samples collected for bacteriological and chemical examination were collected in sterile bottles and analyzed as soon as possible. While working with the collected samples, they were kept in a dark refrigerator. Tests were performed in accordance with Standard Methods.[3]

Coliforms Estimation of coliform group density was made by the multiple fermentation tube technique. Lauryl sulfate broth was used in the presumptive test and positive tubes were confirmed in 2% brilliant green bile broth. The procedures were carried out as prescribed with one exception.

Transfer from positive presumptive tubes to confirmed tubes were made with slender sterile wooden sticks, instead of sterile metal 3mm loops. From appropriate dilution of the sample, five fermentation tubes were innoculated. In most cases, more than three dilutions were set up so the three most valid dilutions could be obtained. The positive tube findings were expressed as Coliform most probable number index per 100 ml. The index numbers were obtained from appropriate tables.

Expression of the coliform MPN index per 100 ml is not a direct count of the bacteria. The estimate of the density is based on the probability of obtaining particular results in a series of fermentation tubes, each innoculated with an appropriate amount of the decimally diluted sample. Prepared tables give an estimate of the bacteria density with 95% confidence limits based on the results of the fermentation tubes.

It has been indicated that the coliform MPN index of replicate tests made on sample having a fixed bacteria density are distributed about the mean density approximately in accordance with a log normal frequency curve. Based on this, replicate determinations on a sample to determine coliform density are expressed as a geometric mean.

The use of a geometric mean as the expression of coliform density rules out the use of tests of significance based on the normal distribution. Tests of significance between means of coliform density in samples are based on non-parametric statistical methods. The non-parametric methods are considered distribution free and can be used when sampling from non-normal populations.

Bacteriophage. Phage used in experiments were f_2 RNA bacteria virus. Cells used to plaque the f_2 phage were E. Coli K-37. Assay of bacteriophage was performed by the agar layer method. Results of the assay were recorded as Plaque Forming Units (PFU) per ml.

Biochemical Oxygen Demand (BOD). BOD determinations were made in a 20^{0} C incubator following standard procedures. Results were expressed as mg/l of five day BOD. (BOD_5)

Chemical Oxygen Demand (COD). COD determinations were made by the potassium dichromate reflux method following standard procedures. Results were expressed as mg/l COD.

Hydrogen Ion. pH determinations were made on a Fisher Accumet Model 210 pH meter. The meter was periodically checked with standard reference solutions.

Ammonia Nitrogen. Ammonia nitrogen determinations were made by the direct nesslerization method following standard procedures. Color measurements were made on a Bausch and Lomb Spectronic 20 colorimeter at 400 Millimicrons (mu). Results were expressed as mg/l ammonia nitrogen.

Nitrate Nitrogen. Nitrate nitrogen determinations were made by the Brucine method following standard procedures. Color measurements were made on the Bausch and Lomb Colorimeter at 410 mu. Results were expressed as mg/l nitrate nitrogen.

Iron. Iron determinations were made by the 1.10 Phenanthroline method. Color developed in the sample was read as percent transmittance at 500 mu in the Bausch and Lomb Colorimeter. Transmittance was compared to a standard curve and the results were recorded as mg/l iron.

Flow. The flow in the tertiary unit was determined by volume discharge calibration of the pump. Flow was expressed as gallons per minute (gpm).

Turbidity. Turbidity measurements were made on a Hach Continuous Reading Surface Scatter Turbidimeter. The unit was calibrated to read in Jackson Turbidity Units (JTU) based on a standard Formazin suspension. The meter was periodically checked at three different values with standard plates.

Ultraviolet Intensity Measurements. Ultraviolet measurements were made on an International Light IL 201 ultraviolet-visible threshold photometer. The photometer operated with a remote vacuum Diode Photosensor type PT 100. The photosensor was calibrated at 2537 A^{o} against a low pressure mercury light source from a spectroradiometer. The spectral response of the photosensor gave a readout in microamperes on the photometer. Readings from the photometer in microamperes multiplied by the calibration factor gave the intensity of the 2537 A^{o} ultraviolet in microwatts per square centimeter (uw/cm^2). Calibration factors for the photosensors were:

1. 122
2. 138
3. 139
4. 147
5. 264

Coagulant aids were available to aid settling of solids in the tertiary tank. Jar tests conducted on sewage samples indicated that use of a cationic polymer alone or in combination with a specially prepared bentonite aided in settling. However, use of the coagulant aids in actual operation was abandoned due to the overload condition in the basic plant. Sludge accumulations in the tertiary tank were pumped to the primary settling tank. The tertiary sludge plus the additional settling obtained in the primary tank by the addition of the coagulant aid generated a heavy volume of sludge. The increased sludge required additional pumping to draw off the primary sludge. This additional load on an already overloaded digestor resulted in a heavy supernatant return to the primary settling tank. The heavy flow of supernatant return to the primary tank resulted in high BOD values in the primary effluent.

SECTION VII

OPERATING PROBLEMS

During the course of the experiments every effort was made to operate the tertiary treatment continuously. There were a number of problems which upset the process and the continuity of the project. In addition to hydraulic overload, the mechanical condition of the basic plant and weather condition were factors.

The problem of hydraulic overload in the secondary plant is indicated by the average flow of 143,000 gpd, with a range of 85,000 to 375,000 plus, in a plant designed for 100,000 gpd. Most of the hydraulic overload was attributed to ground and storm water flow. During periods of rain, flow to the plant increased rapidly.

The combination of high sewage flow and high tide in the Miles River resulted in an inadequate hydraulic gradient in the 8" outfall line. During the period the final sewage effluent backed up in the outfall line.

Equipment in the basic plant had been in use for 15 years prior to the start of the project. During most of the project, the sludge transfer pump was in unsatisfactory condition and the standby pump could not be used.

The steel shell of the secondary settling tank was pitted and corroded. This resulted in short circuits in the secondary settling and did not permit good secondary settling.

Initiation of the split treatment process relieved the hydraulic overload in the aerator and secondary settling tank. Use of the primary settling tank to recirculate sewage added to the overload in the primary settling tank.

Temperature was a factor in operation of the plant. The secondary plant and tertiary plant were constructed above grade and cold weather upset the biological process. In cold weather little biological action took place in the digestor and pumping of primary sludge to the digestor resulted in a heavy supernatant return to the primary tank. When sewage temperature fell below $10^{o}C$, heavy bulking of the activated sludge was experienced. The activated sludge would bulk and continuously purge for several days.

Flow to the tertiary settling unit was steady and the main problem in operation resulted from conditions in the secondary plant. The main problem was bulking of the activated sludge. A Sludge Volume Index of 1,000 was common. The light material was carried into the tertiary settling tank. The material was difficult to settle and use of settling aids created such a volume of sludge that the unit was soon full. Warm weather rather than cold weather affected the use of the tertiary tank.

The tertiary tank was a steel shell set above grade level. Temperature difference between the steel shell and the sewage in the tank resulted in gasification in solids settled on the steel shell. Layers of the settled material would float to the surface and flow thru the U.V. disinfection chamber. Warm weather also produced heavy slime growth in the exposed trough of the settling tank. In warm weather, the slime growth had to be cleaned off daily.

During May, 1969, the split treatment process was started in operation. By June, 1969, the process was brought up to an operating level. For the remainder of June, and during July and August the process performed without interference. On Sept. 5, 1969, the process was voluntarily shut down due to a controversy over a crab and fish kill in the Miles River. On September 15, 1969, the process was put back into operation. Little trouble was experienced in putting the process into full operation. On Sept. 22, 1969, a quantity of gasoline was dumped into the sewage collection system. For several days a gasoline odor permeated from the sewage plant. For two weeks following the gasoline spill the activated sludge spontaneously bulked and interfered with operation of the tertiary unit. From this time until Jan. 10, 1970, the operation performed without upset.

On January 9, 1970, the weather was severely cold and the temperature of the sewage in the plant dropped below 10°C. With the lower temperature the activated sludge bulked. During the cold weather the activated sludge would periodically bulk and continue to purge for several days. The periodic bulking of the activated sludge continued until April 27, 1970.

The end of April marked the beginning of a warming trend and the temperature of the sewage started to increase above 10°C. At this time the activated sludge bulked again and continuously purged until the termination of the project on May 9, 1970.

As indicated in Figure 1, settled sewage from the tertiary tank was directed to the ultraviolet disinfection chamber. From the trough to the disinfection chamber, the direction of flow was directed at right angles into the four parallel troughs in the disinfection chamber. Velocity of sewage flow in the disinfection chamber was low thus permitting settling of solid material. Capacity of the disinfection chamber was 60.8 gallons, and at average operating flows of 30 gallons per minute the velocity in the chamber was .103 ft/sec. With such a low velocity, sewage mixing was not adequate and even the lightest suspended material settled in the chamber.

The sewage level in the disinfection chamber was controlled by a long trough exposed to natural light. Bacteria exposed to ultraviolet and then exposed to visible light had a tendency to recover from the UV damage. The open exposure of the irradiated effluent in the trough would favor photoreactivation of the bacteria.

The U. V. lamps were arranged parallel with the sewage flow. An arrangement whereby the lamps were at right angles to the flow might be more efficient. The U. V. output of the lamp could only be checked on four lamps at any one time. To check the other lamps the unit had to be shut down and the lamps, in turn, put in the end hood and checked for U. V. output.

During periods of high humidity trouble was encountered with the pin connection of the U. V. lamps. Each fixture and pin end on the lamp had to be cleaned and coated with an electrical contact aid. The ultraviolet disinfection unit was outdoors and low temperature reduced the U. V. output of the lamp.

In general, the electrical control panel and meters performed well with the exception of the solenoid operated diversion gate. The electrical components of the gate were housed in a non-watertight cover. Corrosion was heavy and the gate required frequent maintenance.

SECTION VIII

TEST RESULTS AND DISCUSSION

A. STATIC OR BATCH TESTS

Prior to making tests in the ultraviolet disinfection unit, five static tests, conducted as previously described, were run. These tests were intended to:

a) Check on the kinetics of inactivation for coliform bacteria in sewage effluent when exposed to ultraviolet radiation.

b) Determine the level of turbidity which would interfere with reduction of the coliform level to the preset index value.

c) Determine other factors which would interfere with the inactivation of bacteria in sewage effluent.

The data from these tests are given in Appendix C and summarized in Table 3.

The logarithm of the survival ratio of bacteria plotted against the dose of ultraviolet radiation purportedly gives a straight line. For comparison, the survival ratios from the static tests were plotted in a semilogarithm graph as shown in Figure 3. For the test results, the following is indicated

a) a straight line relation does not hold thru the full course of exposure.

b) The inactivation curve for the first four tests is similar with a pronounced tailing effect after 99.99% of the bacteria had been activated.

c) The inactivation curve for the fifth test in which the turbidity level and the ultraviolet absorption were highest is more erratic.

Due to the non-linearity of the inactivation curves, slope functions were not calculated; however, the inactivation curve for the first four tests were similar enough to permit the observation that the decreasing rate of inactivation in each case was similar. This similarity is better indicated by plotting the survival ratio against the time of exposure, as in Figure 4. This also demonstrates that a variation in the average ultraviolet intensity in the range 194-279 uw/cm^2 had little effect on the inactivation of the bacteria.

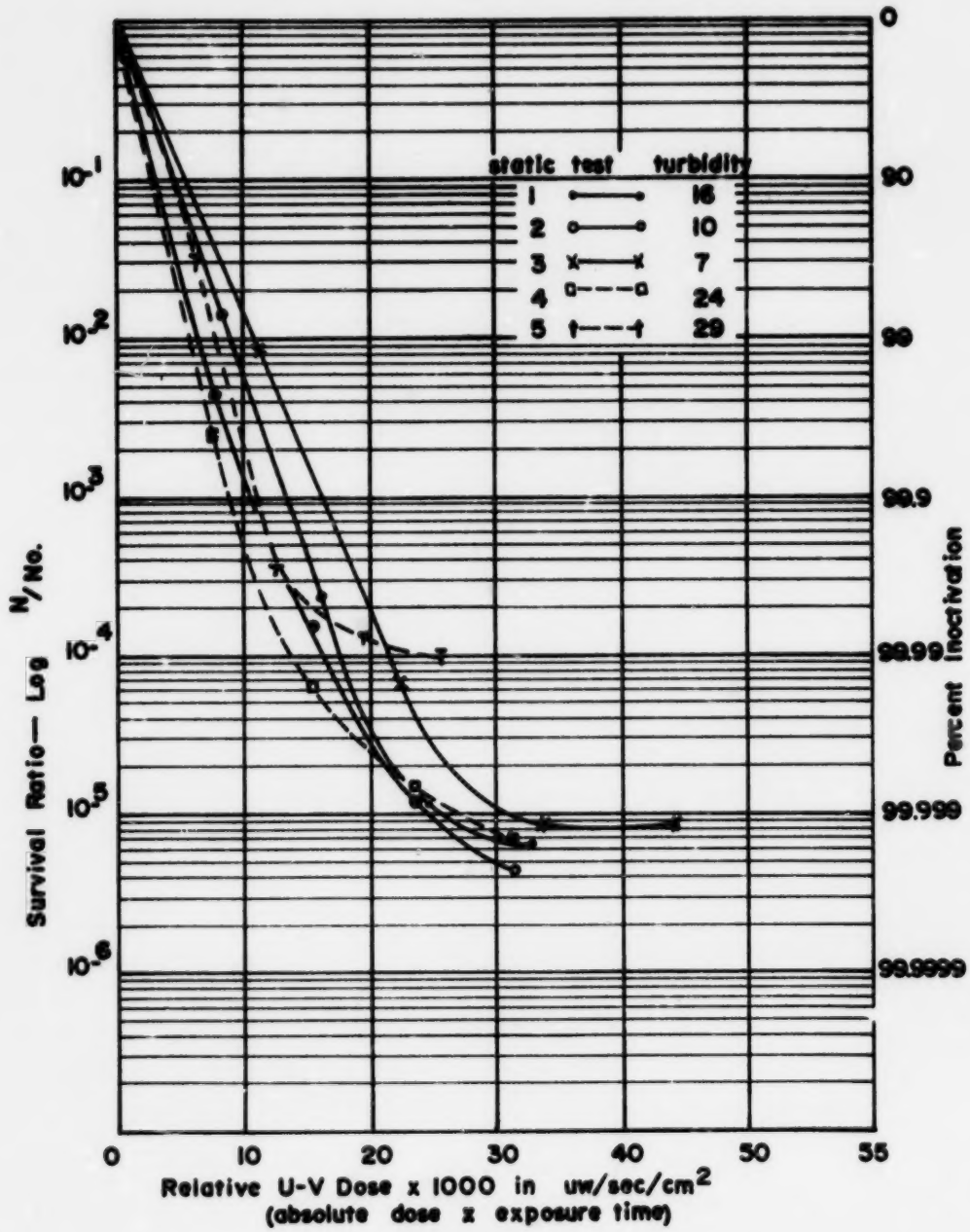

FIG. 3

COLIFORM SURVIVAL CURVES

TABLE 3

DATA FROM STATIC TESTS

(a) Geometric mean of 3 replicate determinations
(b) Geometric mean of 5 replicate determinations

Date	June 9, 1969	June 17, 1969	June 23, 1969	June 30, 1969	July 7, 1969
pH	7.51	7.23	7.23	7.15	7.2
Temperature ^{o}C	23	23	24	26	26
Amm. Nitrogen mg/l	12.5	0	1.3	1.3	4.3
Total Iron mg/l	0.13	0.21	0.22	0.2	0.24
Turbidity JTU	16	10	7	24	29
BOD_5 mg/l	63	21	8	22	36
Absorption /in Coefficient	1.1	1.14	1.0	1.17	1.28
Average absolute Dose uw/cm^2	203	196	279	194	159
Relative U.V. Dose $uw/sec/cm^2$					
40 sec exp	8,120	7,840	11,160	7,760	6,360
80 sec exp	16,240	15,680	22,320	15,520	12,720
120 sec exp	24,360	23,520	33,480	23,280	19,080
160 sec exp	32,480	31,360	44,640	31,040	25,440

Mean Coliform Density and Survival Ratios

Exposure Time Sec.	MPN(a)	N/No	MPN(b)	N/No	MPN(b)	N/No	MPN(b)	N/No	MPN(b)	N/No
0	$7.9x10^{6}$	-	$7.16x10^{5}$	-	$7.27x10^{5}$	-	$8.91x10^{5}$	-	$1.17x10^{6}$	-
40	$1.12x10^{5}$	$1.4x10^{-2}$	$3.19x10^{3}$	$4.4x10^{-3}$	$6.13x10^{3}$	$8.4x10^{-3}$	$2.19x10^{3}$	$2.5x10^{-3}$	$3.85x10^{4}$	$3.3x10^{-2}$
80	$1.9x10^{3}$	$2.4x10^{-4}$	$1.21x10^{2}$	$1.7x10^{-4}$	$4.9x10^{2}$	$6.7x10^{-5}$	$5.5x10^{1}$	$6.2x10^{-5}$	$4.16x10^{2}$	$3.5x10^{-4}$
120	$8.4x10^{1}$	$1.1x10^{-5}$	$9x10^{0}$	$1.3x10^{-5}$	$6x10^{0}$	$8.3x10^{-6}$	$1.3x10^{1}$	$1.5x10^{-5}$	$1.66x10^{2}$	$1.4x10^{-4}$
160	$5.0x10^{1}$	$6.3x10^{-6}$	$3x10^{0}$	$4.2x10^{-6}$	$6x10^{0}$	$8.3x10^{-6}$	$6.0x10^{0}$	$6.7x10^{-6}$	$1.19x10^{2}$	$1.0x10^{-4}$

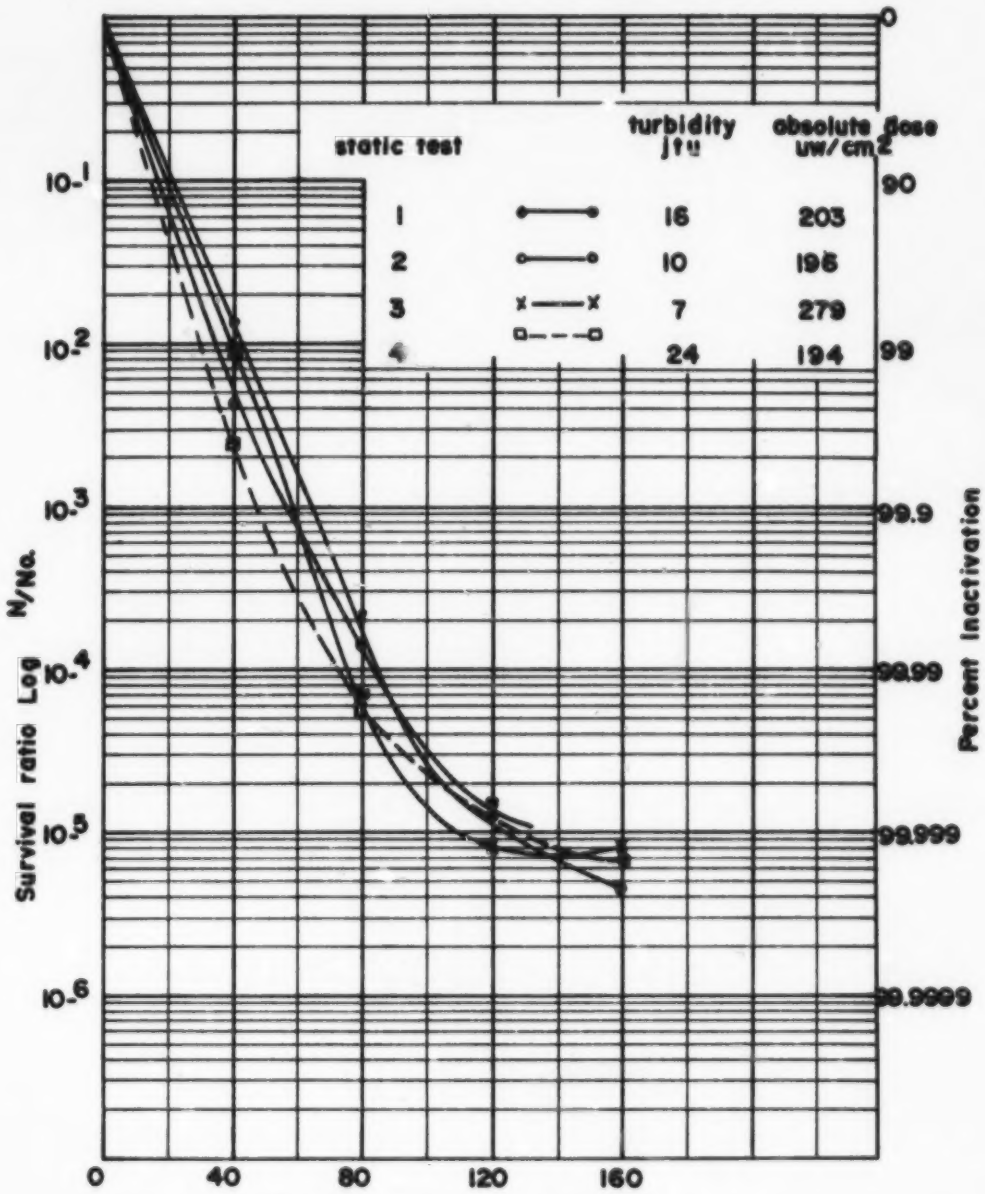

FIG. 4

COLIFORM SURVIVAL CURVES

B. DYNAMIC TESTS

Based on the static experiments, tests were conducted under actual flow conditions in the ultraviolet disinfection chamber. From the static tests it was indicated, except for high initial coliform density and high turbidity, an exposure period of 120 seconds produced an effluent with a coliform MPN index below 70/100 ml. To provide a small safety factor the exposure period was selected at 130 seconds.

Prior to each day's testing, the troughs and ultraviolet chamber were cleaned and flow conditions re-established a minimum of 15 minutes before samples were collected for assay. The ultraviolet lamps were prewarmed for the same minimum period .

The results of the tests from the various days' testing are shown in Appendix D. The exposure period varied from 128 seconds to 130 seconds. Turbidity levels in the independent samples of irradiated effluent varied from 2 to 23 JTU. In Figure 5, the coliform MPN index per 100 ml from 76 independent samples is plotted against the turbidity. From the plotting, it is indicated that for the given conditions of exposure in the ultraviolet chamber, a turbidity level above 11 JTU grossly interferes with the ultraviolet inactivation of the bacteria. Of the 76 samples, 53 samples had a turbidity level below 11 JTU, and 23 samples had a turbidity level above 11 JTU. Of the 53 samples with a turbidity level below 11 JTU, only two samples had a coliform MPN Index per 100 ml over 70. In the samples with a turbidity level over 11 JTU, 13 of the 23 samples had a coliform MPN Index per 100 over 70.
The results of these tests were also compared in another way. Irradiated samples, which had a coliform level below 70/100 ml, were classified as acceptable and unacceptable if the value exceeded 70/100 ml. The results were then plotted against the individual ultraviolet intensity readings and the turbidity value of the sample. This plot is shown in Figure 6. As the residual ultraviolet intensity is reduced and the turbidity value increases, the number of failures increased.

C. U.V. ABSORPTION

To determine the association between ultraviolet absorption, turbidity and organic matter in the sewage, a series of observations were taken. For each observation, the absorption coefficient, turbidity level and organic level was determined. The measure of organic material used was determined by the Chemical Oxygen Demand Test.

The results of the observations are shown in Table 4 and Figure 7. Comparison of the data was made by a programmed step-wise regression analysis. The calculated absorption coefficient was the dependent variable and the COD and turibidity values were the independent variables. The results of the analysis are shown in Table 5.

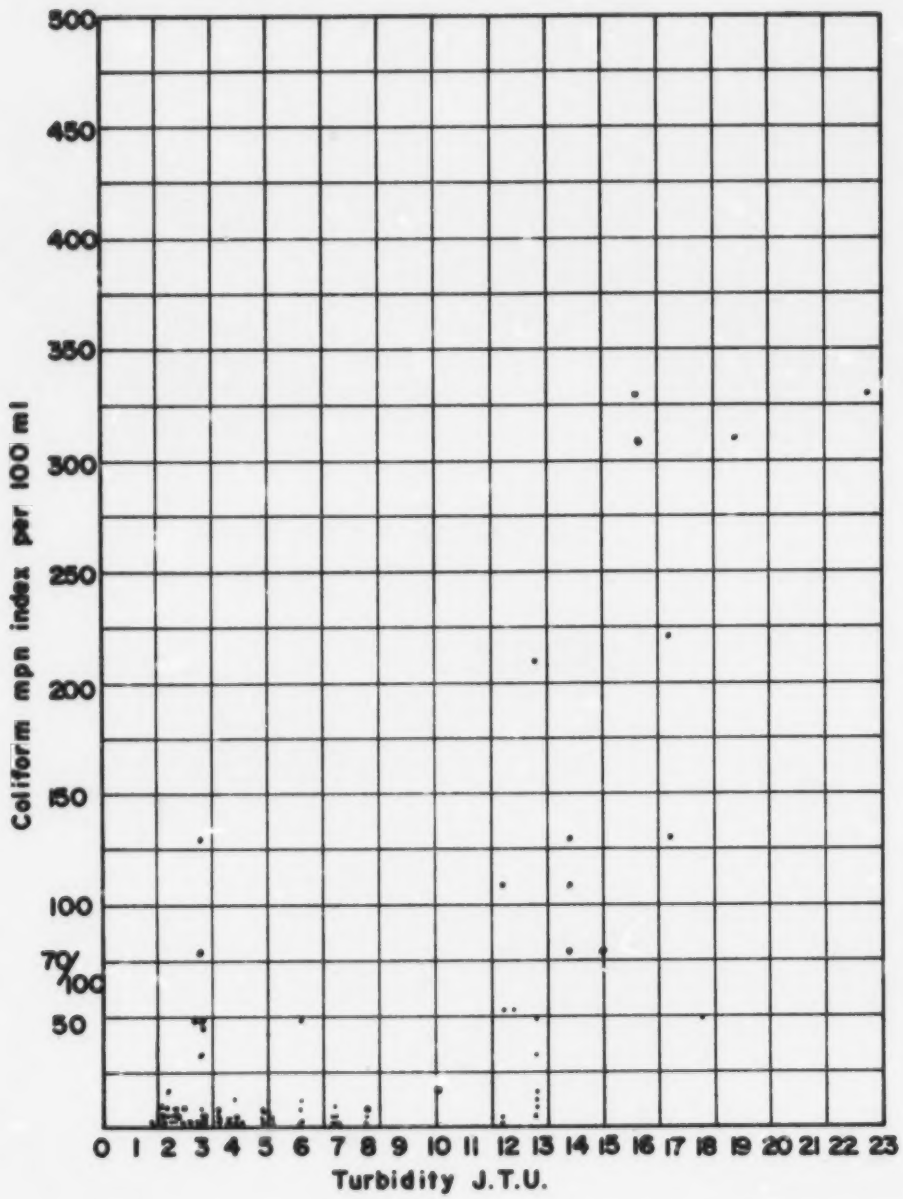

FIG. 5
COLIFORM M.P.N. VS. TURBIDITY FOR
76 DYNAMIC TESTS

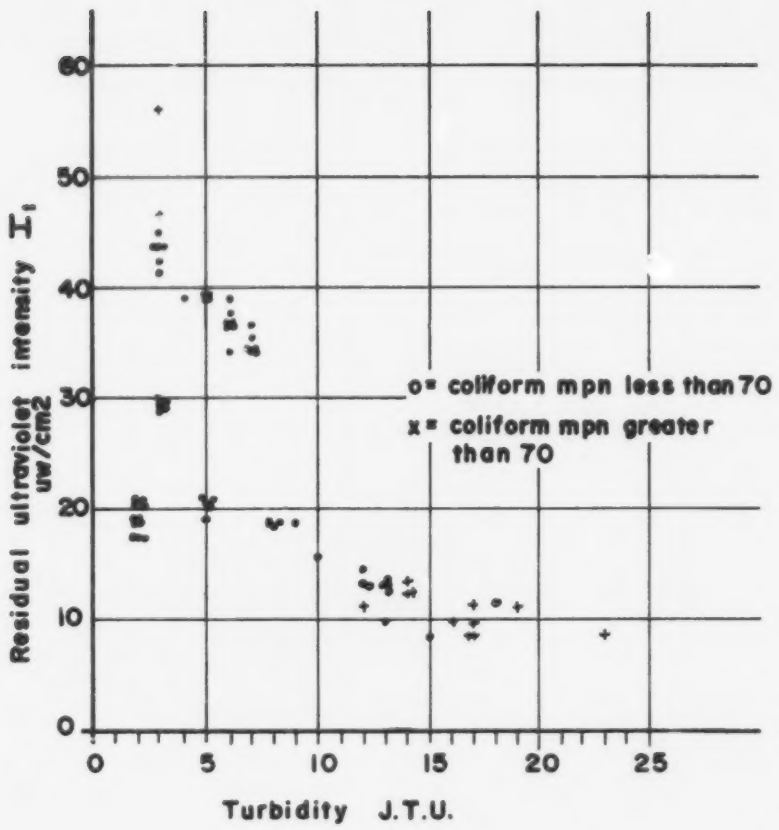

FIG. 6
U-V INTENSITY VS. TURBIDITY
DYNAMIC TESTS

TABLE 4

U-V ABSORPTION COEFFICIENT, COD, AND TURBIDITY DATA

	Absorption Coefficient k/in.	COD mg/l	Turbidity JTU
1	.722	65	10
2	.204	15	3
3	.052	15	1.5
4	.204	20	6.5
5	.718	61	15
6	.569	46	5
7	.604	56	7
8	.722	55	10
9	.718	49	15
10	.356	35	17
11	.551	31	5.5
12	.580	40	7
13	.651	51	6
14	.594	50	6
15	.270	20	2.5
16	.612	44	5.5
17	.558	48	5
18	.708	47	7.5
19	.558	38	4.5
20	.377	23	7
21	.533	41	35
22	.380	20	2

1. Calculated from $I/I_0 = e^{-kd}$

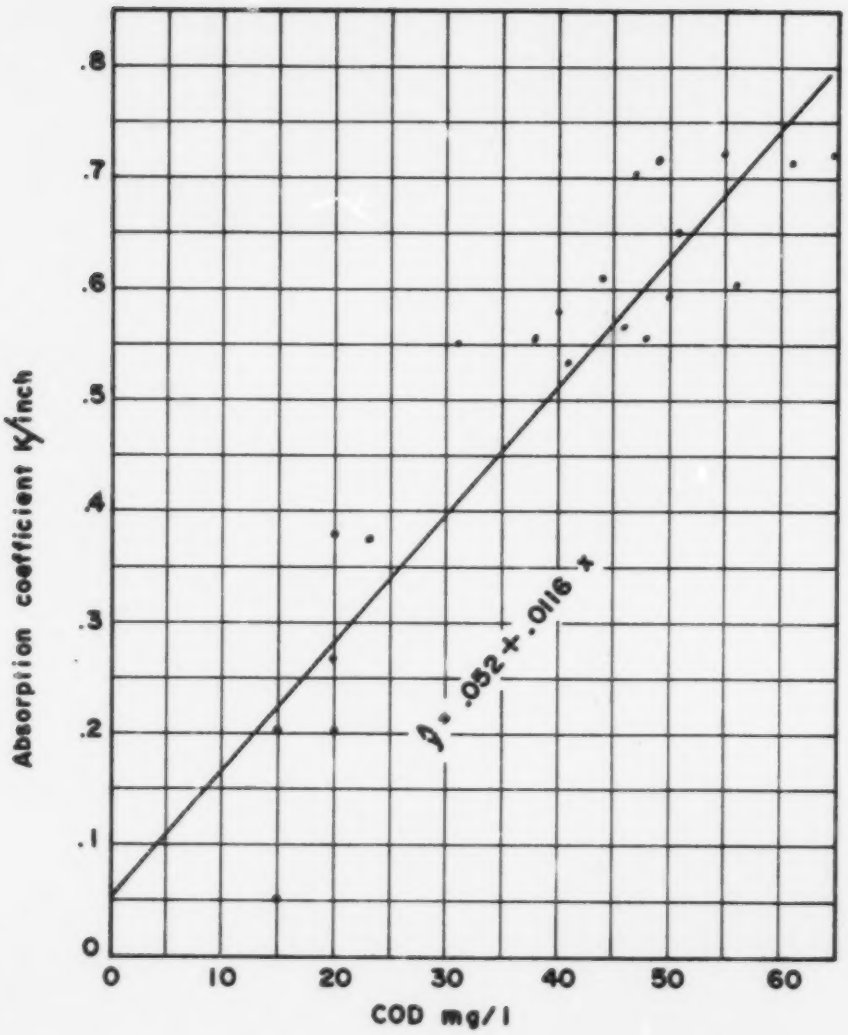

FIG. 7

SAMPLE REGRESSION OF
ABSORPTION ON C.O.D.

TABLE 5

REGRESSION ANALYSIS U-V ABSORPTION, COD, AND TURBIDITY

		Y = absorption		y = C.O.D.	
		X^1 C.O.D.	X^2 Turbidity		X^1 = Turbidity
Total Sum of Squares	.7899			4859.46	
Sum of Square Reduced		.6538	.000345		1359.77
Proportion of Variance of Y Reduced		.8277	.000437		.27982
Partial F		96.0579** (DF 20)	.0483 (DF=19)		7.77085*
Cummulative Sum of Square Reduced		.6538	.6541		1359.77
Cummulative Proportion Reduced		.8277	.8281		.27982
Multiple Correlation Coefficient		.9098	.9100		.52898
F for Analysis of Variance (D, F, = 1,20) (D, F, 2, 19)		96.0579**	45.7676		7.77085
Standard error of estimate		.0825	.0845		13.2282
Compared T		9.80**	-.2197		2.78762**

Significance *P > .01

**P ≤ 1.01

The summary indicates that most of variance of the dependent variable is explained by the organic level and addition of turbidity measures contributed little to the regression. The partial F. test of the null hypothesis $B_1 = B_2 = 0$, indicates a significant relation of COD to absorption and the turbidity values contribute little. The multiple correlation coefficient of absorption versus COD is .9098 and was only increased to .91 by additon of the turbidity.

The proportion of the variance of the absorption coefficient that can be attributed to the linear regression on COD would be 82.77% and increased .04% with the inclusion of turbidity values in the regression.

The indication that about 83% of the variance of absorption coefficient can be attributed to its linear regression on COD does not exclude a relation between COD and turbidity. A linear regression analysis between COD and turbidity gave a correlation coefficient of .529, indicating about 28% of the variance of the COD values can be attributed to the regression as turbidity.

Turbidity has some effect on the absorption of ultraviolet by sewage, but the indication is that a measure of the COD of the sewage would be a better indicator.

Artificially added turbidity would not envelope the bacteria and therefore would not have as much of an interference effect on U.V. efficiency (or penetration) as would pinpoint floc.

D. MIXING IN U-V CHAMBER

Comparison of the dynamic test results with the static tests indicated that lower levels of suspended material during the dynamic tests affected the coliform level in the irradiated effluent. This would indicate that mixing in the ultraviolet chamber is not as efficient as in the static test system. The baffles in the ultraviolet chamber were set so the flow went over all baffles. The alternative arrangement, without extensive modification of the chamber, was to set the baffle so the flow went under alternate weirs.

The baffles were set in the two settings and for each arrangement a series of independent samples were taken. A sample of the sewage before irradiation was taken and then four samples taken of the irradiated effluent. This was repeated twice for each baffle arrangement. The turbidity during the test varied from 12 to 23 JTU. The flow rate, and thus the exposure, during the test was uniform. The data is summarized in Table 6.

TABLE 6

EFFECT OF FLOW PATTERN BY BAFFLE CHANGES

Over-Under Baffles X			Over Baffles Y		
Turbidity JTU	Coliform MPN Index Per 100 ml	Geometric Mean	Turbidity JTU	Coliform MPN Index Per 100 ml	Geometric Mean
Before Exposure					
-	2780×10^{2}		-	330×10^{4}	
-	330×10^{4}	9.57×10^{5}	-	790×10^{3}	1.61×10^{6}
After Exposure					
17	490×10^{0}		14	79×10^{0}	
18	49×10^{0}		13	210×10^{0}	
19	310×10^{0}		13	49×10^{0}	
17	130×10^{0}		17	221×10^{0}	
14	109×10^{0}		17	490×10^{0}	
23	330×10^{0}		12	109×10^{0}	
14	130×10^{0}		15	79×10^{0}	
16	330×10^{0}	$1,87 \times 10^{2}$	13	33×10^{0}	1.12×10^{2}

Non-parametric test of means in unpaired replicates.

E ranks (Ty) = 55.5 E ranks (Tx) = 80.5

T is smaller of Tx and Ty. $T = Ty^{2} = 55.5$

For nx=ny=8 the critical value of T = 52

(P=.10 Two sided Test)

Ty = 55.5 T.10 = 52. No significant difference between means of two samples.

Samples of the non-irradiated sewage effluent, during the period the baffles were set in the over-under position, indicate the geometric mean coliform density was 9.57×10^5 per 100 ml. After irradiation, the geometric mean coliform density was 1.87×10^2 per ml. Turbidity measures on the samples averaged 17 JTU. During the period the baffles were in the regular position, the geometric mean coliform density of the non-irradiated sewage was 1.61×10^6. After irradiation, the geometric mean coliform density was 1.12×10^2. Turbidity measures on the samples averaged 14 JTU.

A comparison of the two treatment means indicates there was no significant ($P = .05$ two-sided test) difference between the means of the two samples.

E. pH VALUE OF SEWAGE.

To check if pH variation in sewage would affect inactivation of the coliform bacteria, a static experiment was conducted. A sample of tertiary sewage effluent was collected, well mixed and divided into two aliquots. One aliquot was exposed to ultraviolet irradiation with samples drawn at time intervals for coliform determination. The pH of the second aliquot was lowered by adding buffered pH tablets. The aliquot was then exposed to ultraviolet irradiation under the same conditions as the first aliquot. The same procedure was carried out on a second sample of tertiary sewage effluent.

The results of the determinations made on the sewage samples are shown in Appendix E. In the first sewage sample, the pH was 7.5 and changed to 6.0 with the buffered pH tablets. pH of the second sewage sample was 7.39 and 5.95 after addition of the tablets. Calculated survival ratios of coliform bacteria plotted against the relative ultraviolet dose are shown in Figure 8.

The inactivation curve for each sample indicated the characteristic tailing effect. The decreasing rate of decrease between the two samples was not similar; however, the rate of decrease between the aliquots of each sample was similar.

Attempts to raise the pH of sewage effluent to about 8.5 with buffered pH tablets produced a change in the sewage upon addition of the buffer tablets. A fine precipitate was formed and the sewage had a distinct opaque cast. Inactivation experiments at higher pH values were not carried out.

F. BACTERIA DENSITY

To demonstrate the effect of the bacteria density of sewage subjected to ultraviolet irradiation, under given conditions of exposure, two similar experiments were conducted.

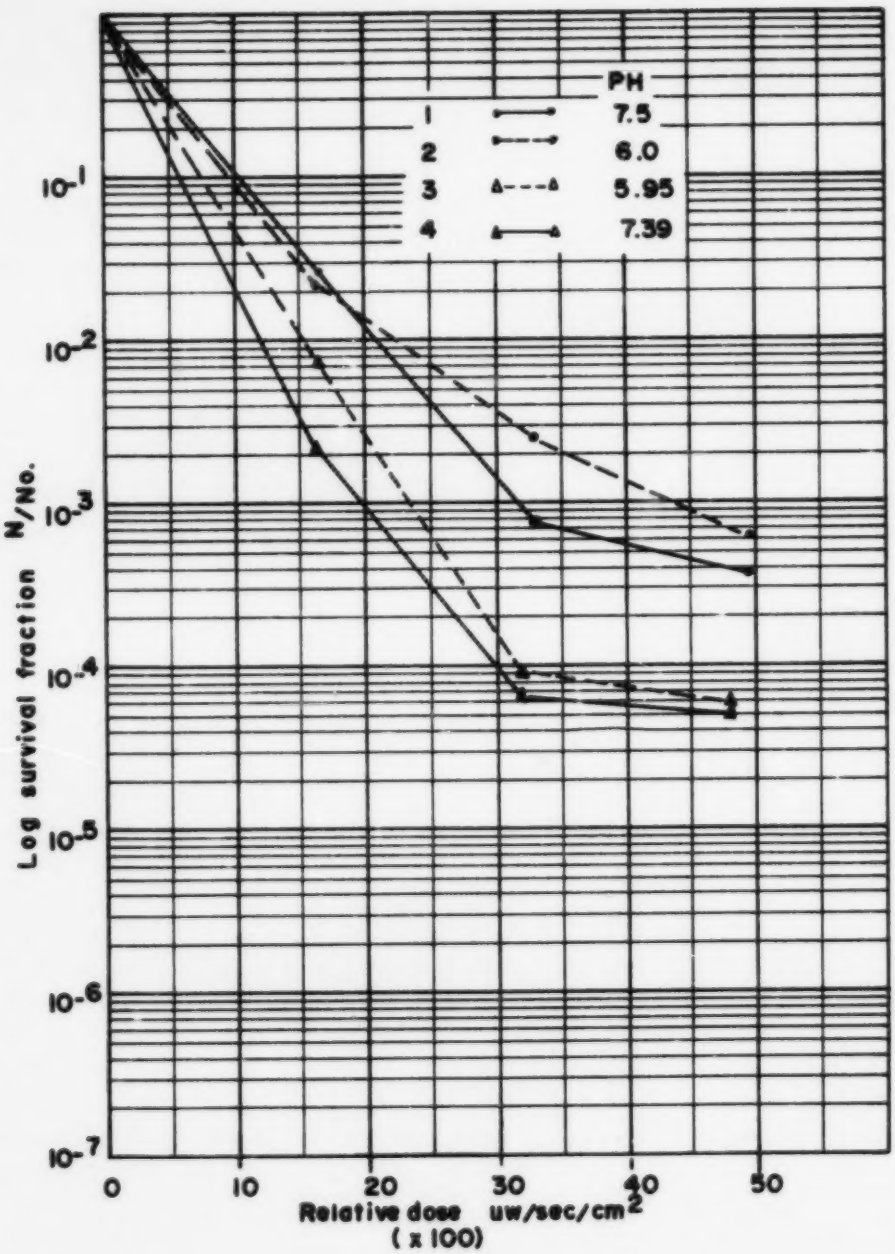

FIG. 8
SURVIVAL RATIO VARIATION
WITH PH

A sample of tertiary sewage effluent was collected, well mixed and divided into two aliquots. One aliquot was exposed to ultraviolet irradiation under static conditions. Coliform determinations were made on the sample before ultraviolet exposure and after 160 seconds exposure. The bacteria density of the second aliquot was increased with an inoculum of K-37 E Coli cells and then subjected to similar static ultraviolet irradiation. The experiment was repeated on a second sample of tertiary sewage effluent.

The results of the two experiments are summarized in Table 7. In the first experiment, the geometric mean density of the non-seeded sample was 4.26×10^5 per 100 ml and 93 per 100 ml after 160 seconds exposure. The geometric mean coliform density of the seeded aliquot was 1.01×10^8 per 100 ml and 2.3×10^4 per 100 ml, after a similar exposure.

In the second experiment, the geometric mean coliform density of the non-seeded sample was 9.54×10^5 per 100 ml and 21 per 100 ml after 160 seconds exposure. The geometric mean density of the seeded aliquot before and after 160 second exposure was 12.4×10^6 and 2.76×10^3 per 100 ml respectively. In each case, the sample with the higher initial bacteria density had a higher number of surviving bacteria.

G. SHIELDING OF BACTERIA BY SUSPENDED MATTER IN IRRADIATED SEWAGE EFFLUENT

To determine if an increased level of suspended material in a sewage sample under given conditions of exposure afforded the bacteria a significant degree of protection several experiments were conducted. With the ultraviolet disinfection unit in operation, a series of independent samples of the irradiated effluent were taken. Coliform determinations were made on the samples following standard procedures. Each sample was shaken the prescribed 25 times before the proper amount was withdrawn for innoculations into fermentation tubes. After this procedure was carried out the remainder of the sample was mixed for one minute in a high speed mixer. After the machine mixture, proper amounts of the sample were again taken for coliform determinations.

The above procedure was carried out on a series of irradiated effluent samples in three independent tests. In each run the turbidity level of the sewage was different. The results are summarized in Table 8.

In the first series of samples with an average turbidity value of 4 JTU (range 3 to 6 JTU) there was no significant difference between the two treatment sample means. The two series of samples, with higher turbidity levels, indicated the means of the sample assayed with mixing as prescribed by standard procedures was significantly smaller (significance level of $P=0.10$).

TABLE 7

EFFECT OF BACTERIA DENSITY

Exposure Time Seconds	Coliform No Seed	MPN G.M.	Index Per 100 ml Seeded Aliquot	G.M.
Nov. 10, 1969				
0	230×10^3	4.26×10^5	790×10^5	1.01×10^8
0	790×10^3		1300×10^5	
160	109×10^0	9.3×10^1	230×10^2	2.3×10^4
160	79×10^0		230×10^2	
AVG. U.V. DOSE = 80 uw/cm^2				
Nov. 17, 1970				
0	1300×10^3	9.54×10^5	700×10^4	1.24×10^7
0	700×10^3		2210×10^4	
160	21×10^0	2.1×10^1	230×10^1	2.76×10^3
160	22×10^0		230×10^1	
AVG. U.V. DOSE = 94 uw/cm^2				

TABLE 8

COLIFORM DETERMINATIONS MADE ON IRRADIATED SEWAGE SAMPLES
AFTER DIFFERENT METHODS OF MIXING

Exposure Time 114 Seconds			Exposure Time Seconds			Exposure Time Seconds		
Coliform MPN Index per 100 ml			Coliform MPN Index per 100 ml			Coliform MPN Index per 100 ml		
Turb. JTU	Reg. Mixing	Machine Mix	Turb. JTU	Reg. Mixing	Machine Mix	Turb. JTU	Reg. Mixing	Machine Mix
6	8	14(a)	7	8	11(b)	21	49	49(b)
5	8	8	7	5	33	23	33	49
5	23	7	7	49	130	22	33	79
4	11	2	7	5	23	23	33	79
4	5	11	7	11	17	22	79	109
4	13	13	7	13	13	22	79	23
4	22	13	8	13	33	22	17	49
3	2	5	7	13	33	21	23	79
3	2	7	10	46	130	20	13	23
3	8	8	8	13	33	20	11	23
3	5	7	8	33	49	20	13	33
3	0	8	8	79	21	20	33	33
4	Avg.							

(a) No significant difference between sample means (P=0.10 two sided test)

(b) Means of samples assayed with mixing prescribed by standard procedures significantly smaller. (P=0.10 two sided test.

H. PHOTOREACTIVATION

With the ultraviolet disinfection unit in operation a sample of the irradiated effluent was collected and replicate coliform determinations made. The sample was divided into two aliquots. One aliquot was exposed to the visible light and the second was kept in the dark. After one hour exposure each sample was assayed for coliform. The results of these tests are summarized in Table 9.

From the results it is indicated that bacterial multiplication in the aliquot exposed to sunlight immediately after U.V. exposure continued at an exponential rate. The density of bacteria in the aliquot kept in the dark declines, but then multiplied after exposure to sunlight. A comparison is indicated in Figure 10.

The calculated relative dose of U.V. in the first photoreactivation experiment was 14,514 uw/sec/cm^2 and in the second experiment was 7811 uw/sec/cm^2. In each case it was obvious that some of the bacteria had not received a lethal dose of U.V. and exposure to visible light favored continued multiplication.

Two experiments were carried out to determine the dose at which subsequent exposure of the sample to visible light would not favor photoreactivation. These tests were conducted with static exposure of the sewage. The sample was assayed before exposure to U.V., after an exposure of 33,000 uw/sec/cm^2, the irradiated sample after 1 hour exposure to visible light. The results are summarized in Table 10. In test one, no increase in coliform density was indicated in the irradiated sample exposed to visible light. In test two multiplication of the bacteria is indicated in the irradiated sample after exposure to visible light. From these test results it is indicated a dose in excess of 33,000 uw/sec/cm^2 would be necessary to prevent photoreactivation.

I. BACTERIOPHAGE

To check the kinetics of phage inactivation by ultraviolet radiation, several static experiments were conducted. A sample of tertiary effluent was collected, and innoculated with f_2 phage. The sample was well mixed and exposed to ultraviolet radiation. At time intervals samples were withdrawn and assayed for phage.

The results of these experiments are shown in Appendix F and summarized in Table 11. The survival ratio from each experiment is plotted in Figure 11.

From the semilog plot, within the range of exposure, it is indicated that first order kinetics apply for f_2 exposed to ultraviolet radiation.

TABLE 9

EFFECT OF PHOTOREACTIVATION

Coliform MPN Index per 100/ml*

Calculated Dose	After Exposure	After 1 Hr. light exp.	Sample Kept in Dark
14,514 uw/sec/cm^2	21	17[illegible]	9

*Geometric mean of 7 replicate determinations.

From these results it is obvious that exposure to visible light after ultraviolet exposure favors the continued multiplication of the bacteria, where as a decline in density was noted in the sample kept in the dark.

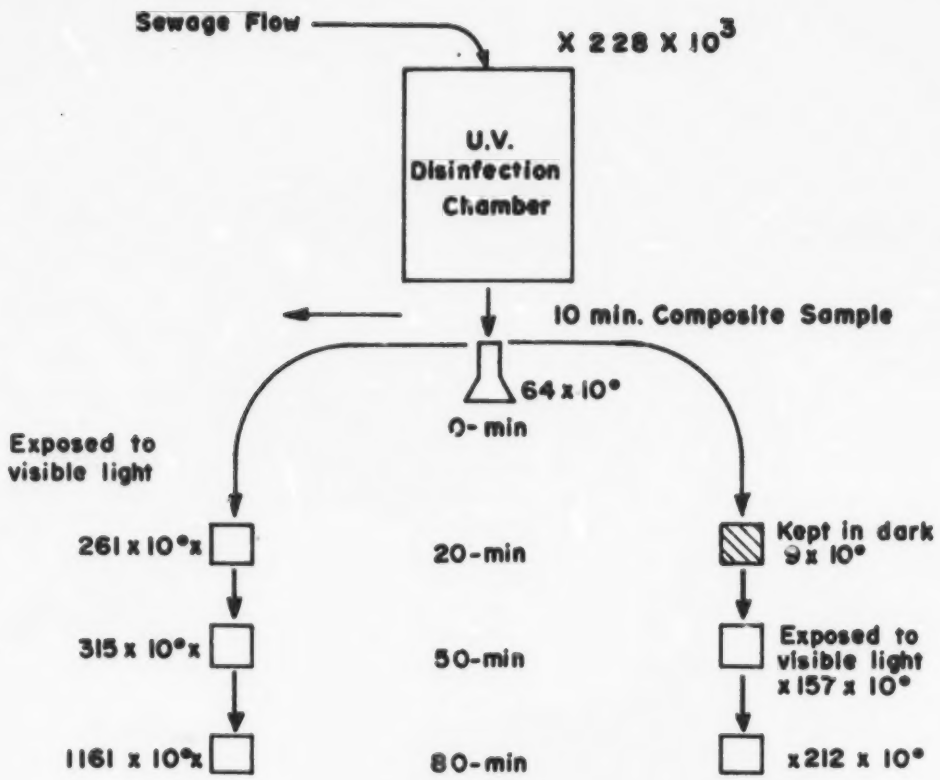

FIG. 9

COLIFORM SURVIVAL IN LIGHT AND DARK

To further check on the photoreactivation of ultraviolet irradiated bacteria, a test was conducted as indicated in Figure 9. Results of the coliform assay for each sampling point is also indicated.

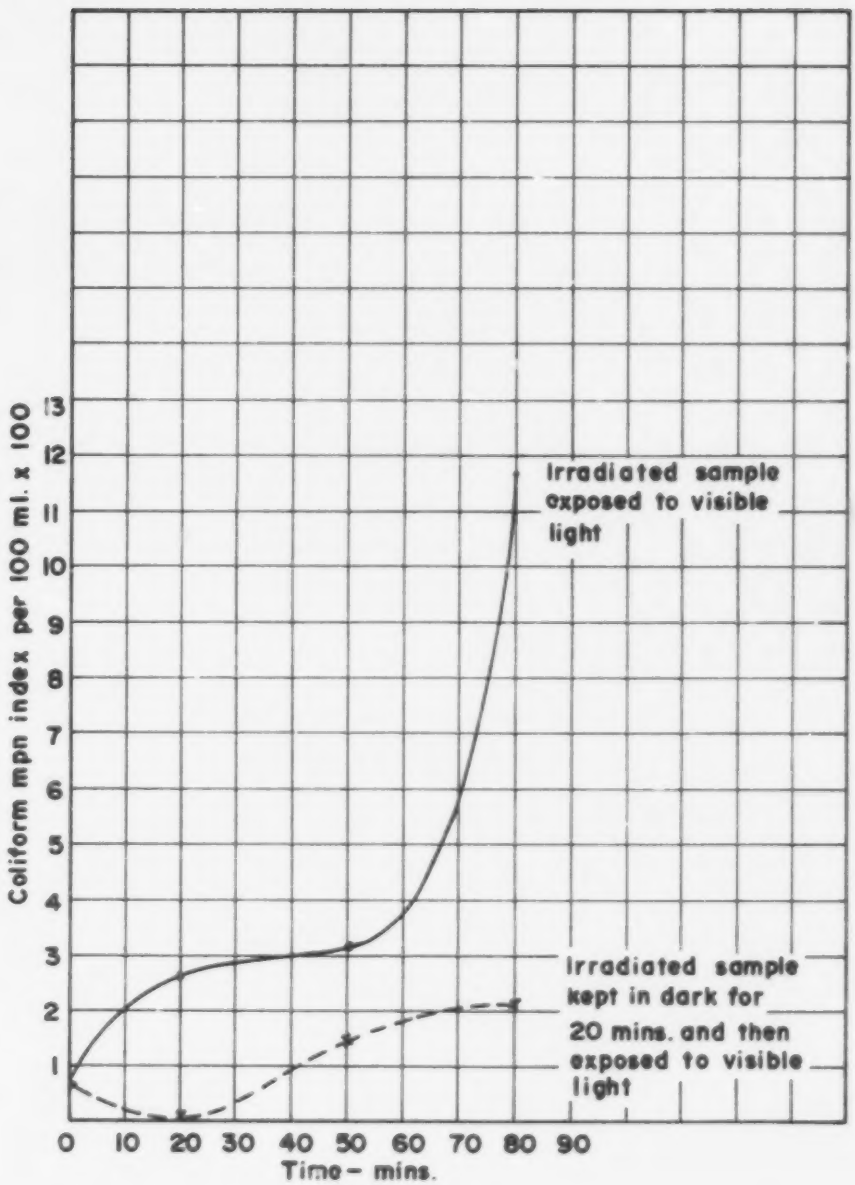

FIG. 10

COLIFORM SURVIVAL IN LIGHT AND DARK

TABLE 10

EFFECT OF PHOTOREACTIVATION AT HIGH U.V. EXPOSURES

TEST 1		TEST 2	
Coliform MPN Index per 100 ml	Geometric Mean	Coliform MPN Index per 100 ml	Geometric Mean
Sample Before Irradiation			
230×10^3	230×10^3	230×10^3	276×10^3
230×10^3		330×10^3	
Sample After U.V. Exposure 33,000 uw/sec/cm^2			
2×10^0	2×10^0		2×10^0
2×10^0		2×10^0	
Irradiated Sample After One Hour Exposure			
2×10^0	2×10^0	11×10^0	9×10^0
2×10^0		8×10^0	
Non-Irradiated SampleAfter One Hour Exposure			
130×10^3	173×10^3	330×10^3	270×10^3
230×10^3		221×10^3	

TABLE 11

f_2 PHAGE INACTIVATION

	1	2	3	4
Date	Nov. 5, 1969	Nov. 12, 1969	Nov. 25, 1969	Dec. 4, 1969
pH	7.48	7.25	7.19	7.35
Temperature ^{o}C	18	17	14	9
Amm. Nitro. mg/l	0	0	0	0
Total Iron mg/l	0.31	0.36	0.33	0.31
Turbidity JTU	9	10	6	3
Absorption Coefficient	.92	.92	.996	.92
Average absolute Dose uw/cm^2	111	75	108	99

Exp. Time Sec.	RELATIVE DOSE ULTRAVIOLET $uw/sec/cm^2$			
40	4440	3000	4320	3960
80	8880	6000	8640	7920
120	13320	9000	12960	11880
160	17760	12000	17280	15840

PLAQUE COUNTS AND SURVIVAL RATIOS

	PFU	N/No	PFU	N/No	PFU	N/No	PFU	N/No
0	$1x10^7$	-	$1.63x10^5$	-	$8.9x10^4$	-	$1.44x10^5$	-
40	$2.34x10^6$	$2.3x10^{-1}$	$8.55x10^3$	$5.2x10^{-2}$	$2.42x10^4$	$2.7x10^{-1}$	$3.45x10^4$	$2.4x10^{-1}$
80	$3.20x10^5$	$3.2x10^{-2}$	$1.03x10^3$	$6.3x10^{-3}$	$2.19x10^3$	$2.5x10^{-2}$	$5.45x10^3$	$3.8x10^{-2}$
120	$5.40x10^4$	$5.4x10^{-3}$	$1.05x10^2$	$6.4x10^{-4}$	$3.35x10^2$	$3.8x10^{-3}$	$1.01x10^3$	$7.0x10^{-3}$
160	$1.14x10^4$	$1.1x10^{-3}$	$1.00x10^1$	$6.1x10^{-5}$	$4x10^1$	$4.5x10^{-4}$	$1.5x10^2$	$1.0x10^{-3}$

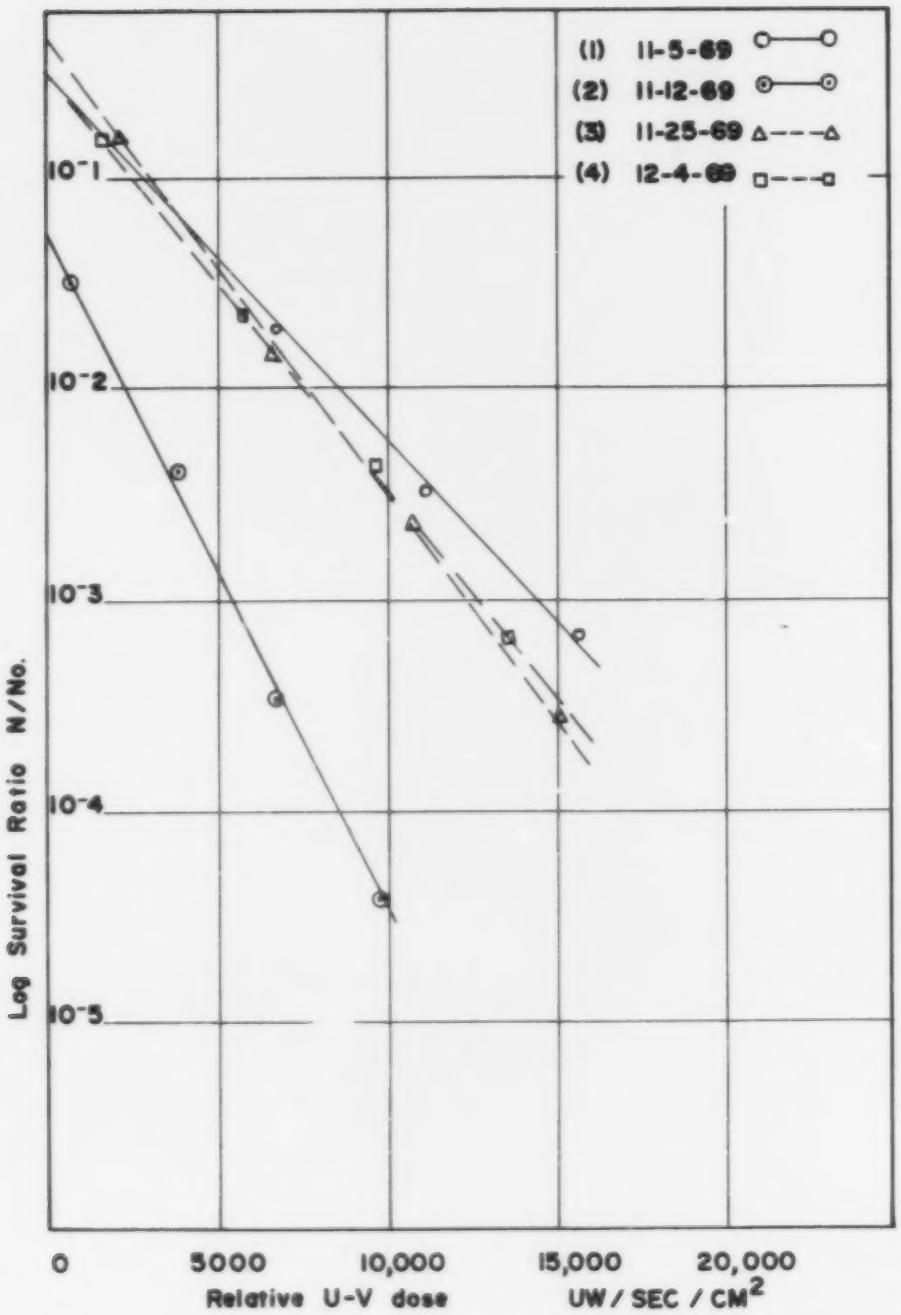

FIG. 11

INACTIVATION CURVE FOR F_2 PHAGE 42

J. BACTERIOPHAGE PHOTOREACTIVATION

To check on the photoreactivation of f_2, several experiments were conducted on tertiary sewage effluent seeded with f_2 phage and exposed to ultraviolet radiation in the disinfection chamber. The sampling plan is indicated by Figure 12.

The results of these experiments are summarized in Table 12. The results indicate no change in phage density in the irradiated sample exposed to visible light or kept in the dark. However, the controls showed no significant multiplication indicating the lack of a suitable host.

Another experiment conducted with K-37 host cells added to the f_2 phage seed, and to the irradiated sample. The results of this test is shown in Table 13.

B.U. Sample – Before Ultraviolet Treatment

A.U. Sample – After Ultraviolet Treatment

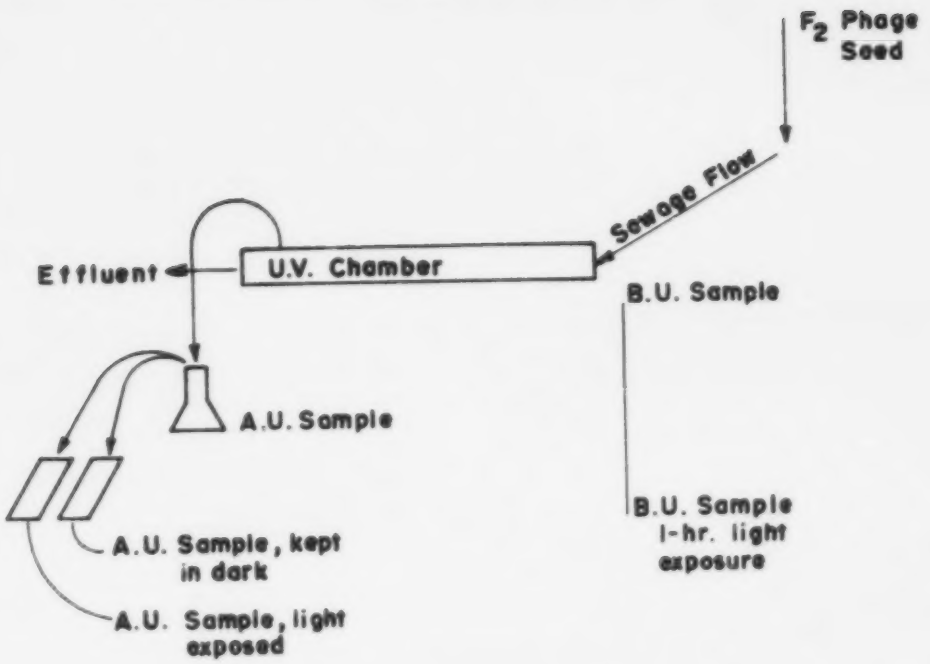

FIG.12

SAMPLING PLAN FOR PHAGE PHOTOREACTIVATION TEST

TABLE 12

f_2 PHAGE PHOTOREACTIVATION

SAMPLE	PFU/ml 1	2	3
Sample before exposure (BU)	15,100	4250	6050
Sample after exposure (AU)	0	12	0
Irradiated sample exposed to visible light for 1 hr. (AU)	0	13	0
Irradiated sample exposed to visible light for 2 hr. (AU)	-	-	0
Irradiated sample kept in dark for one hour	0	15	-
Sample (BU) exposed to visible light for one hour (control)	13,300	8770	6150
Calculated minimum relative dose uw/sec/cm^2	11,160	11,210	1885

TABLE 13

Photoreactivation of f_2 phage with added K-37 host cells.

	PFU/ml
Sample before exposure with f_2 phage + K-37 host cells BU	4.3×10^6
Irradiated sample (AU)	1545
Irradiated sample + K-37 cells exposed to visible light for one hr.	2200
Sample (BU) exposed to visible light for one hr. (control)	4.7×10^8
Ultraviolet Dose mw/sec/cm^2	3480

From this test it is indicated that phage subjected to a sub-lethal dose of ultraviolet radiation and exposed to visible light in the presence of a suitable host would continue to multiply.

SECTION X

REFERENCES

1. U. S. Public Health Service Publication No. 1500, "National Register of Shellfish Production Areas".

2. Bradley, E. F., "Advanced Wastewater Control System," Journal, Water Pollution Control Federation.

3. "Standard Methods for the Examination of Water and Wastewater", 12th Edition, American Public Health Association, New York, 1965.

4. U. S. Army Chemical Corps, Technical Report BL 28, "Use of Ultra-violet Radiation in Microbiological Laboratories".

5. Luckiesh, M., and Holladay, L. L., "Disinfecting Water by Means of Germicidal Lamps", General Electric Review, 47, pp 45-50, 1944.

6. U. S. Public Health Service Publication No. 33, Part I, "National Shellfish Sanitation Program Manual of Operations - Sanitation of Shellfish Growing Areas".

7. General Electric Co., Large Lamp Division, "Germicidal Lamps", Catalog, p 122.

SECTION XI

GLOSSARY

Bacteriophage - Viruses which are parasitic to bacteria.

B.O.D. (Biochemical Oxygen Demand) - Amount of oxygen used by microorganisms in the stabilization of organic matter at 20^{o} in 5 days.

C.O.D. (Chemical Oxygen Demand) - The measure of the oxygen demand of sewage in a two hour sulfuric acid-dichromate reflexing.

Coliform Organisms - A group of bacteria recognized as indicators of fecal pollution.

Germicidal Ultraviolet Plant - Ultraviolet lamp that has most of the energy generated at a predominant wavelength of 2537 Angstrom units $I=I_{o}e^{-Kd}$.

J.T.U. - A measure of turbidity in Jackson Turbidity Units.

K_1 - Absorption Coefficient Per Inch - The fraction of the remaining ultraviolet intensity absorbed per inch of solution, described by the equation $I=I_{o}e^{-Kd}$.

I_1 - Ultraviolet radiation intensity, microwatts per square centimeter.

I_o - Initial ultraviolet radiation intensity.

e - Base of natural logarithms.

M.P.N. - An estimate of the number of coliform organisms per 100 milliliters of sample based on probability formulas.

SECTION XII

APPENDICES

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APPENDIX A

April 1, 1966

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

Division of Environmental Engineering and Food Protection

Policy Statement on:

USE OF THE ULTRAVIOLET PROCESS FOR DISINFECTION OF WATER

The use of the ultraviolet process as a means of disinfecting water to meet the bacteriological requirements of the Public Health Service Drinking Water Standards is acceptable provided the equipment used meets the criteria described herein.

In the design of a water treatment system, care must be exercised to insure that all other requirements of the Drinking Water Standards relating to Source and Protection, Chemical and Physical Characteristics, and Radioactivity are met. (In the case of an individual water supply, the system should meet the criteria contained in the "Manual of Individual Water Supply Systems", Public Health Service Publication No. 24). The ultraviolet process for disinfecting water will not change the chemical and physical characteristics of the water. Additional treatment, if otherwise dictated, will still be required, including possible need for residual disinfectant in the distribution system.

Color, turbidity and organic impurities interfere with the transmission of ultraviolet energy and may decrease the disinfection efficiency below levels required to insure destruction of pathogenic organisms. It may be necessary to pretreat some supplies to remove excessive turbidity and color. In general, units of color and turbidity are not adequate measures of the decrease that may occur in ultraviolet energy transmission. The organic nature of materials present in waters can give rise to significant transmission difficulties. As a result, an ultraviolet intensity meter is required to measure the energy levels to which the water is subjected.

Ultraviolet treatment does not provide residual bactericidal action. Therefore, the need for periodic flushing and disinfection of the water distribution system must be recognized. Some supplies may require routine chemical disinfection, including the maintenance of a residual bactericidal agent throughout the distribution system.

Criteria for the Acceptability of an Ultraviolet Disinfecting Unit

1. Ultraviolet radiation at a level of 2,537 Angstrom units must be applied at a minimum dosage of 16,000 microwatt-seconds per square centimeter at all points throughout the water disinfection chamber.

2. Maximum water depth in the chamber, measured from the tube surface to the chamber wall, shall not exceed three-inches.

3. The ultraviolet tubes shall be:

   a. Jacketed so that a proper operating tube temperature of about 105°F. is maintained, and

   b. The jacket shall be of quartz or high silica glass with similar optical characteristics.

4. A flow or time delay mechanism shall be provided to permit a two minute tube warm-up period before water flows from the unit.

5. The unit shall be designed to permit frequent mechanical cleaning of the water contact surface of the jacket without disassembly of the unit.

6. An automatic flow control valve, accurate within the expected pressure range, shall be installed to restrict flow to the maximum design flow of the treatment unit.

7. An accurately calibrated ultraviolet intensity meter, properly filtered to restrict its sensititivy to the disinfection spectrum, shall be installed in the wall of the disinfection chamber at the point of greatest water depth from the tube or tubes.

8. A flow diversion valve or automatic shuf-off valve shall be installed which will permit flow into the potable water system only when at least the minimum ultraviolet dosage is applied. When power is not being supplied to the unit, the valve should be in a closed (failsafe) position which prevents the flow of water into the potable water system.

9. An automatic, audible alarm shall be installed to warn of malfunction or impending shutdown if considered necessary by the Control or Regulatory Agency.

10. The materials of construction shall not impart toxic materials into the water either as a result of the presence of toxic constituents in materials of construction or as a result of physical or chemical changes resulting from exposure to ultraviolet energy.

11. The unit shall be designed to protect the operator against electrical shock or excessive radiation.

As with any potable water treatment process, due consideration must be given to the reliability, economics and competent operation of the disinfection process and related equipment, including:

1. Installation of the unit in a protected enclosure not subject to extremes of temperature which could cause malfunction.

2. Provision of a spare UV tube and other necessary equipment to effect prompt repair by qualified personnel properly instructed in the operation and maintenance of the equipment.

3. Frequent inspection of the unit and keeping a record of all operations, including maintenance problems.

APPENDIX B

OPERATING INSTRUCTIONS

INSTRUMENT AND SAFETY CONTROL RELAY BOX

GENERAL

The relay control box is designed to provide the necessary safeguards to prevent discharge of improperly treated waste into the bay. The switches and relays are arranged so that the diversion gate will be dropped in any of several eventualities: power failure, excess turbidity, low ultraviolet light intensity, failure of one of the sixteen ultra-violet lamps, or high water in the sterilization chamber. If one or more of these things occur, the solenoid holding the diversion gate will be de-energized permitting the gate to drop, diverting the flow to the holding lagoon. Except in the case of power failure, when the gate has dropped, the solenoid again will be energized to lock the gate down until the trouble has been corrected. In all cases, the battery operated alarm will be sounded and will continue to sound until the silencing switch is operated, or until the battery fails.

There are five pilot lights designed to alert the operator as to the type of trouble encountered. These lights cannot be turned off, nor the gate locked up, until the trouble has been corrected. The operation of each circuit will be detailed below.

In addition, the relay box contains the timer to control the operation of the two samplers and the chemical feed pump, in accordance with the flow, as indicated by the flowmeter. The timer is field adjustable so that the desired percentage of sampler or pump on time can be set as experience dictates.

SAMPLERS AND CHEMICAL FEED PUMP

The two samplers and one chemical feed pump are controlled by the flow meter and a relay and timer in the relay box. There is also a disconnect switch in the box with which to turn the pumps on or off. The timer consists of two plug-in time delay relays, each with double pole, double throw contacts. When the flowmeter indicates approximately 400 gallons have passed the measuring point, it closes a contact for 25 milli-seconds. This in turn energizes a relay in the relay box through a normally closed contact on the timer. When the time delay relays are energized, depending on the time setting, the sampler and chemical feed pump can be operated for a period up to about sixty seconds. Either the samplers or the chemical feed pump can be shut off first. The time delay relay with the longest time setting will reset the timers ready for the next pulse from the flowmeter.

TURBIDITY METER

The turbidity meter measures the turbidity of the liquid and if the turbidity exceeds the set point closes a contact to operate the turbidity relay in the relay box. This relay seals itself in, so that a subsequent decrease in turbidity has no effect until the manual reset button is pressed. At the same time the turbidity relay operates, it de-energizes the gate solenoid permitting the gate to drop, diverting the flow to the lagoon. At this time, the excess turbidity pilot light will turn on and after the gate has dropped, the gate down pilot light will turn on and the alarm bell will ring. If in fact the turbidity has returned to normal, pushing the reset button, this will permit the gate to be raised and locked up. This will also de-energize the relay and turn off the excess turbidity light. However, if the turbidity is still high, pushing the reset button will have no effect.

LOW ULTRA-VIOLET INTENSITY

There are four photo-cells which sense the intensity of the ultra-violet light penetrating the liquid. Through a switch located outside the relay box and by closing the instrument panel, any one of these sensors can be connected to the UV analyser in the instrument panel. Whenever the intensity sensed falls below the set point, as determined by the analyser, a contact in the analyser will open, de-energizing the intensity relay in the relay box. This will, in turn, light the low intensity pilot light, and de-energize the gate solenoid. However, to prevent false indications caused by solids flowing over the photo-cell, the relay box contains a time delay relay, which prevents operation of the intensity relay for a period of ten seconds. Thus, a momentary loss of intensity will not cause diversion with the subsequent alarm conditions, but a loss exceeding ten seconds, as set on the pneumatic time delay relay, will cause diversion.

ULTRA-VIOLET LAMP FAILURE

There are sixteen ultra-violet lamps under four hoods to provide sterilization of the effluent. These lamps, with ballasts draw approximately nine amperes. If one lamp fails, the current will be reduced approximately 0.5 amperes. The current meter - which in fact is a volt meter operating in conjunction with the transformer in the relay box - will sense this drop in current and cause the gate to drop. The meter is adjustable so that if at some future date it is found that less than sixteen lamps are needed, the lamp failure protection can still be obtained. Operation of the reset button will not have any effect unless the faulty lamp has been replaced. The reset button must be operated to re-energize the lamp relay and permit the gate to be raised. All the time the UV Lamps are on, an orange pilot light on the relay box will be lit, and will go out in the event of failure of the lamp circuit. This lamp is also used as a "power on, conditions normal" indicator.

Inside the relay box there are two "defeat" switches; one for the intensity and one for lamp current. Since the UV Lamps take time to warm up and reach final operating current, it is desirable to prevent false indications of lamp failure during this warm-up period. This can be accomplished by placing the current defeat switch in the "defeat" position, returning it to normal after the lamps have been on for approximately fifteen minutes. The intensity defeat switch can be used to maintain operation normally in the event of trouble with the analyser. Unless these switches are in the "defeat" position, diversion by either low intensity or lamp failure must be corrected before the relays can be reset and the diversion gate locked up.

Each ultra-violet lamp hood, containing four lamps, is equipped with a Microswitch, arranged so that if any hood is lifted, all sixteen lamps will go off. This is to protect the operator from exposure to the extremely intense ultra-violet light. Operation of the hoods will, of course, cause diversion of the flow, unless the operator is authorized to place the defeat switches in the "defeat" position when raising the hoods for normal maintenance.

HIGH WATER ALARM

Since the mixture of water and electricity is dangerous, two probes are provided to sense the rise of water level in the ultra-violet chamber. These probes operate on 12 volts AC and draw a total of two milliamperes current, which makes them intrinsically safe. When water bridges between the probes, it completes a circuit between the highwater alarm transformer and the rectifier. This energizes the rectifier which is connected to the high water sensing relay. This is a sensitive relay, operating on 2 milliamperes and 12 volts DC. This relay, in turn, operates the high water alarm relay. The high water alarm relay, when energized, turns off the UV lamps and turns on the high water alarm pilot light. The loss of UV, in turn, operates the intensity relay to cause diversion of the flow to the lagoon.

DIVERSION GATE

Whereas the diversion gate, obviously, is not in the relay box, it's operation is controlled by the seventh relay in the box and will be discussed here. The gate relay is normally energized through the contacts on the turbidity, intensity and lamp current relays. If any of them is operated, the circuit to the gate relay is opened, de-energizing the relay. The gate locking solenoid is energized when the gate relay is energized under normal conditions. Thus, when the gate relay is de-energized, the gate solenoid is also de-energized, permitting the gate to drop. When the gate does in fact drop, a Microswitch senses the gate in the down position and through a normally closed contact on the gate relay again energizes the gate solenoid to lock the gate in the down position. Located conveniently to the gate is a push button with one normally closed and one normally open contact. All current to the gate solenoid goes through this push button, using the normally closed contacts.

Thus, when the conditions are returned to normal, it is necessary to push this button to unlock the gate so that it can be raised. At the same time, the normally open contacts close, re-energizing the gate relay to re-energize the gate solenoid after the gate has been raised, and the push button released. If conditions are not normal, and all affected circuits return to normal by means of the reset buttons, the gate solenoid will not be energized after the gate has been raised, and the gate will immediately drop again.

Whenever the gate relay is de-energized, the alarm will ring. However, the gate down lamp will not light unless the gate has in fact dropped and been locked. Thus, if at any time the alarm is ringing, and the gate down light is not lit, it can be assumed the gate has, for some reason, failed to drop completely and it will be necessary to examine the gate first to remove any obstruction so that flow will be diverted while cause for diversion is being corrected. On the cover of the relay box is an alarm silencing switch to turn off the alarm and preserve the battery.

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

June 9, 1969

Turbidity JTU	16
pH	7.51
Temperature ^{o}C	23
Ammonia Nitrogen mg/l	12.5
Total Iron mg/l	0.13
BOD_5 mg/l	63

Ultraviolet Intensity
Measured with
Probe 1 C.F. - 122

Trough 1 I_o ua	4.7
Trough 1 I^o ua	.21
Trough 2 I_1 ua	.24
Depth inches	2.81

Absorption Coefficient

$$e^{-kd} = I_1/I_o$$

$$e^{-kd} = .21/4.7$$

$$k = 1.1/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I./e^{-kd}$$

$$I_o = .24/.0446$$

$$I_o = 5.38$$

Calculated average intensity in Trough 2.

$$Iave = I_o \frac{(1 - e^{-kd})}{kd}$$

$$Iave = 5.38 \frac{(1 - .044)}{3.1}$$

$$Iave = 1.66$$

Average absolute dose

Iave x C.F.

1.66 x 122

203 uw/cm^2

Calculated relative dose for exposure period.

203 uw/cm^2	x 40	sec	= 8120	$uw/sec/cm^2$
"	x 80	"	=16240	"
"	x120	"	=24360	"
"	x160	"	=32480	"

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: June 9, 1969

#	Exposure Time Sec.	Coliform Index MPN/100 ml.	Geometric Mean of MPN Index	Survival Ratio N/No
60901A	0	790×10^4		
B	0	790×10^4	7.9×10^6	
C	0	790×10^4		
60902A	40	16090×10^1		
B	40	5420×10^1	1.12×10^5	1.4×10^{-2}
C	40	16090×10^1		
60903A	80	1720×10^0		
B	80	1720×10^0	1.90×10^3	2.4×10^{-4}
C	80	2300×10^0		
60904A	120	49×10^0		
B	120	130×10^0	8.4×10^1	1.1×10^{-5}
C	120	94×10^0		
60905A	160	49×10^0		
B	160	79×10^0	5.0×10^1	6.3×10^{-6}
C	160	33×10^0		

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: June 17, 1969

Turbidity JTU	10
pH	7.23
Temperature ^{o}C	23
Ammonia Nitrogen mg/l	0
Total Iron mg/l	0.21
BOD_5 mg/l	21

Ultraviolet Intensity
Measured With
Probe 1 C.F. = 12.2
Trough 1 I_o ua = 4.4
Trough 1 I^o ua = .18
Trough 2 I_1 ua = .22
Depth inches = 2.81

Absorption coefficient

$e^{-kd} = I_1/I_o$

$e^{-kd} = .18/4.4$

$k = 1.14/inch$

Calculated I_o in Trough 2 where exposure was made

$I_o = I_1/e^{-kd}$

$I_o = .22/.0409$

$I_o = 5.33$

Calculated average intensity in Trough 2

$$Iave = I_o \left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iave = 5.38 \left(\frac{1 - .0409}{3.2}\right)$$

$Iave = 1.61$ mg

Average absolute dose

Iave x C.F.

1.61 x 122

196 uw/cm^2

Calculated relative dose for exposure period

196 uw/cm^2 x 40 sec = 7840 $uw/sec/cm^2$
" x 80 " =15630 "
" x120 " =23520 "
" x160 " =31360 "

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: June 17, 1969

#	Exposure Time Sec.	Coliform Index MPN/100 ml.	Geometric Mean of MPN Index	Survival Ratio N/No
61701A	0	1410×10^3		
B	0	1090×10^3		
C	0	700×10^3	7.16×10^5	
D	0	1700×10^3		
E	0	250×10^3		
60702A	40	278×10^1		
B	40	330×10^1		
C	40	221×10^1	3.19×10^3	4.4×10^{-3}
D	40	490×10^1		
E	40	330×10^1		
61703A	80	221×10^0		
B	80	130×10^0		
C	80	172×10^0	1.21×10^2	1.7×10^{-4}
D	80	109×10^0		
E	80	49×10^0		
61704A	120	7×10^0		
B	120	5×10^0		
C	120	11×10^0	9×10^0	1.3×10^{-5}
D	120	14×10^0		
E	120	13×10^0		
61705A	160	0		
B	160	2×10^0		
C	160	5×10^0	3×10^0	4.2×10^{-6}
D	160	2×10^0		
E	160	5×10^0		

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

June 23, 1969

Turbidity JTU	7
pH	7.25
Temperature ^{o}C	24
Ammonia Nitrogen mg/l	1.3
Total Iron mg/l	0.22
BOD_5 mg/l	8

Ultraviolet Intensity
Measured With
Probe 1 C.F. 122
Trough 1 I_o ua = 4.3
Trough 1 I_1 ua = 0.24
Trough 2 I_1 ua = 0.38
Depth inches = 2.81

Absorption Coefficient

$$e^{-kd} = I_1/I_o$$

$$e^{-kd} = 0.24/4.3$$

$$k = 1.0/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I/e^{-kd}$$

$$I_o = 0.38/.0558$$

$$I_o = 6.81 \text{ ua}$$

Calculated average intensity in Trough 2

$$Iave = I_o \frac{(1 - e^{-kd})}{kd}$$

$$Iave = 6.81 \frac{(1 - .0558)}{2.8}$$

$$Iave = 2.29 \text{ ua}$$

Average absolute dose

Iav x C. F.
2.29 x 122
279 uw/cm^2

Calculated relative dose for exposure period.

279 uw/cm^2 x 40 sec. = 11160 uw/sec/cm^2
" x 80 " = 22320 "
" x120 " = 33480 "
" x160 " = 44640 "

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: June 23, 1969

#	Exposure Time Sec.	Coliform Index MPN/100 ml.	Geometric Mean of MPN Index	Survival Ratio N/No
62301A	0	1300×10^3		
B	0	330×10^3		
C	0	790×10^3	7.27×10^5	
D	0	1300×10^3		
E	0	460×10^3		
62302A	40	1300×10^1		
B	40	172×10^1		
C	40	460×10^1	6.13×10^3	8.4×10^{-3}
D	40	490×10^1		
E	40	1720×10^1		
62303A	80	22×10^0		
B	80	79×10^0		
C	80	70×10^0	49×10^1	6.7×10^{-5}
D	80	49×10^0		
E	80	49×10^0		
62304A	120	8×10^0		
B	120	6×10^0		
C	120	5×10^0	6×10^0	8.3×10^{-6}
D	120	13×10^0		
E	120	2×10^0		
62305A	160	5×10^0		
B	160	0		
C	160	9×10^0	6×10^0	8.3×10^{-6}
D	160	5×10^0		
E	160	5×10^0		

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

June 30, 1969

Turbidity JTU	24
pH	7.15
Temperatuve ^{o}C	26
Ammonia Nitrogen mg/l	1.3
Total Iron mg/l	0.2
BOD_5 mg/l	22

Calculated average intensity in Trough 2.

$$I_{ave} = I_o \frac{(1 - e^{-kd})}{kd}$$

$$I_{ave} = 5.44 \frac{(1 - .0349)}{3.3}$$

$$I_{ave} = 1.59 \text{ ua}$$

Ultraviolet Intensity Measured With
Probe 1 C.F. 122
Trough 1 I_o ua = 4.3
Trough 1 I_1 ua = .15
Trough 2 I_1 ua = .19
Depth Inches = 2.81

Average absolute dose
Iave x C.F.
1.59 x 122
194 uw/cm^2

Absorption Coefficient

$$e^{-kd} = I/I_o$$

$$e^{-kd} = 0.15/4.3$$

$$k = 1.17/\text{inch}$$

Calculated relative dose for exposure period

194 uw/cm^2 x 40 sec. = 7760 $uw/sec/cm^2$
" x 80 " =15520 "
" x120 " =23280 "
" x160 " =31040 "

Calculated I_o in Trough 2 where exposure was made.

$$I_o = I/e^{-kd}$$

$$I_o = .19/.0349$$

$$I_o = 5.44$$

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: June 30, 1969

#	Exposure Time Sec.	Coliform Index MPN/100 ml.	Geometric Mean of Coliform Index	Survival Ratio N/No
63001A	0	1720×10^3		
B	0	1720×10^3		
C	0	790×10^3	8.91×10^5	
D	0	490×10^3		
E	0	490×10^3		
63002A	40	170×10^1		
B	40	330×10^1		
C	40	80×10^1	2.19×10^3	2.5×10^{-3}
D	40	230×10^1		
E	40	490×10^1		
63003A	80	33×10^0		
B	80	33×10^0		
C	80	49×10^0	5.5×10^1	6.2×10^{-5}
D	80	120×10^0		
E	80	79×10^0		
63004A	120	8×10^0		
B	120	5×10^0		
C	120	7×10^0	1.3×10^1	1.5×10^{-5}
D	120	49×10^0		
E	120	23×10^0		
63005A	160	2×10^0		
B	160	17×10^0		
C	160	5×10^0	6.0×10^0	6.7×10^{-6}
D	160	5×10^0		
E	160	13×10^0		

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date: July 7, 1969

Turbidity JTU	29
pH	7.2
Temperature ^{o}C	26
Ammonia Nitrogen mg/l	4.3
Total Iron mg/l	0.24
BOD_5 mg/l	36

Ultraviolet intensity measured with
Probe 1 C.F. = 122
Trough 1 I_o ua = 3.7
Trough 1 I_1 ua = 0.1
Trough 2 I_1 ua = .13
Depth inches = 2.81

Absorption Coefficient

$$e^{-kd} = I/I_o$$

$$e^{-kd} = 0.10/3.7$$

$$k = 1.28/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = 0.13/.027$$

$$I_o = 4.81 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iave = I_o \left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iave = 4.81 \left(\frac{1 - .027}{3.6}\right)$$

$$Iave = 1.3 \text{ ua}$$

Average absolute dose
Iave x C.F.
1.3 x 122
159 uw/cm^2

Calculated relative dose for exposure period.

159 uw/cm^2	x 40 sec.	= 6360	uw/sec/cm^2
"	x 80 "	=12720	"
"	x120 "	=19030	"
"	x160 "	=25440	"

APPENDIX C

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

Date:

#	Exposure Time Sec.	Coliform Index MPN/100 ml.	Geometric Mean of Coliform Index	Survival Ratio N/No
70701A	0	790×10^3		
B	0	790×10^3		
C	0	1720×10^3	1.17×10^6	
D	0	940×10^3		
E	0	2210×10^3		
70702A	40	172×10^2		
B	40	278×10^2		
C	40	490×10^2	3.85×10^4	3.3×10^{-2}
D	40	1300×10^2		
E	40	278×10^2		
70703A	80	490×10^0		
B	80	230×10^0		
C	80	490×10^0	4.16×10^2	3.5×10^{-4}
D	80	460×10^0		
E	80	490×10^0		
70704A	120	278×10^0		
B	120	490×10^0		
C	120	172×10^0	1.66×10^2	1.4×10^{-4}
D	120	130×10^0		
E	120	41×10^0		
70705A	160	230×10^0		
B	160	130×10^0		
C	160	79×10^0	1.19×10^2	1.0×10^{-4}
D	160	94×10^0		
E	160	109×10^0		

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	(1) LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA	I_1 UW/CM^2	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. UA /L	BOD_5 UA /L	pH	TEMP. °C
71401	AU No. UV	28.3	-	-	-	-	1720×10^2	-	2.4	-	7.12	27
02	"	"	-	-	-	-	1300×10^2	-	"	-	"	"
03	"	"	-	-	-	-	700×10^2	-	"	-	"	"
04	AU	"	129	1	.32	39	13×10^0	4	"	-	7.25	"
05	"	"	"	"	.32	"	2×10^0	5	"	-	"	"
06	"	"	"	"	.32	"	2×10^0	5	"	-	"	"
07	"	"	"	"	.32	"	2×10^0	5	"	-	"	"
08	"	"	"	"	.32	"	0	5	"	-	"	"
09	"	"	"	"	.32	"	49×10^0	6	"	-	"	"
10	"	"	"	"	.30	36.6	2×10^0	6	"	-	"	"
11	"	"	"	"	.30	"	11×10^0	6	"	-	"	"
12	"	"	"	"	.28	34.2	2×10^0	6	"	-	"	"
13	"	"	"	"	.31	37.8	0	6	"	-	"	"
14	"	"	"	"	.30	36.6	8×10^0	6	"	-	"	"
15	"	"	"	"	.30	"	2×10^0	6	"	-	"	"
16	"	"	"	"	.30	"	2×10^0	7	"	-	"	"
17	"	"	"	"	.29	35.4	2×10^0	7	"	-	"	"
18	"	"	"	"	.28	34.2	8×10^0	7	"	-	"	"
19	"	"	"	"	.28	34.2	5×10^0	7	"	-	"	"
20	"	"	"	"	.28	34.2	5×10^0	7	"	-	"	"
21	"	"	"	"	.28	34.2	2×10^0	7	"	-	"	"

(1) LOCATION AU = After Ultraviolet Exposure
BU = Before Ultraviolet Exposure

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA	I_1 UW/CM^2	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. UA/L	BOD_5 UA/L	pH	TEMP. ^{0}C
92314	AU	28.0	130	1	.11	13.4	49×10^0	13	14.2			23
15	"	"	"	"	.07	8.5	221×10^0	17	"			"
16	BU	"	-	-	-	-	790×10^3	-	13.5	61	7.45	"
17	AU	"	130	1	.07	8.5	490×10^0	17	14.2			"
18		"	"	"	.09	11.0	109×10^0	12	"			"
19		"	"	"	.07	8.5	79×10^0	15	"			"
20		"	"	"	.08	9.8	33×10^0	13	"			"
112401	BU	28.6	-	-	-	-	330×10^3	-	0	12	6.99	15
02	AU	"	128	4	.14	20.6	5×10^0	5	"	-	7.01	"
03	BU	"	-	-	-	-	230×10^3	-	"	12	6.99	"
04	AU	"	128	4	.13	19.1	2×10^0	5	"	-	7.01	"
05	BU	"	-	-	-	-	330×10^3	-	"	12	6.99	"
06	AU	"	128	4	.14	20.6	2×10^0	5	"	-	7.01	"
07	BU	"	-	-	-	-	330×10^3	-	"	12	6.99	"
08	AU	"	128	4	.14	20.6	5×10^0	5	"	-	7.01	"
09	BU	"	-	-	-	-	230×10^3	-	"	12	6.99	"
10	AU	"	128	4	.14	20.6	5×10^0	5		-	7.01	"

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA.	I_1 UW/CM^2	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. UA/L	BOD_5 UA/L	pH	TEMP. ^{0}C
120301	BU	28.2	-	-	-	-	490×10^3	-	0	7	7.23	12
02	AU	"	130	4		29.4	0	3	"	-	7.29	"
03	BU	"	-	-	-	-	1300×10^3	-	"	7	7.23	"
04	AU	"	130	4	.2	29.4	0	3	"	-	7.29	"
05	BU	"	-	-	-	-	700×10^3	-	"	7	7.23	"
06	AU	"	130	4	.2	29.4	0	3	"	-	7.29	"
07	BU	"	-	-	-	-	330×10^3	-	"	7	7.23	"
08	AU	"	130	4	.2	29.4	0	3	"	-	7.29	"
09	BU	"	-	-	-	-	330×10^3	-	"	7	7.23	"
10	AU	"	130	4	.2	29.4	0	3	"	-	7.29	"
120801	BU	28.6	-	-	-	-	330×10^3	-	0	14	7.19	12
02	AU	"	128	4	.14	20.6	2×10^0	2	"	-	7.25	"
03	BU	"	-	-	-	-	330×10^3	-	"	14	7.19	"
04	AU	"	128	4	.14	20.6	0	2	"	-	7.25	"
05	BU	"	-	-	-	-	1300×10^2	-	"	4	7.19	"
06	AU	"	128	4	.14	20.6	8×10^0	2	"	-	7.25	"
07	BU	"	-	-	-	-	330×10^3	-	"	4	7.19	"
08	AU	"	128	4	.14	20.6	0	2	"	-	7.25	"
09	BU	"	-	-	-	-	1720×10^2	-	"	4	7.19	"
10	AU	"	128	4	.14	20.6	17×10^0	2	"	-	7.25	"
11	BU	"	-	-	-	-	790×10^2	-	"	4	7.19	12.5
12	AU	"	128	4	.13	19.1	0	2	"	-	7.25	"
13	BU	"	-	-	-	-	1300×10^3	-	"	4	7.19	"
14	AU	"	128	4	.13	19.1	2×10^0	2	"	-	7.25	"
15	BU	"	-	-	-	-	330×10^3	-	"	4	7.19	"

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA	I_1 UW/CM^2	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. UA/L	BOD_5 UA/L	pH	TEMP. °C
120816	AU	28.1	128	4	.13	19.1	5×10^0	2	"	-	7.25	12.5
17	BU	"	-	-	-	-	230×10^3	-	"	4	7.19	"
13	AU	"	128	4	.13	19.1	2×10^0	2	"	-	7.25	"
19	BU	"	-	-	-	-	490×10^3	-	"	4	7.19	"
20	AU	"	128	4	.12	17.6	0	2	"	-	7.25	"
21	BU	"	-	-	-	-	1410×10^2	-	"	4	7.19	"
22	AU	"	128	4	.12	17.6	2×10^0	2	"	-	7.25	"
23	BU	"	-	-	-	-	1300×10^2	-	"	4	7.19	"
24	AU	"	128	4	.12	17.6	5×10^0	2	"	-	7.25	"
42001	BU	28	-	-	-	-	330×10^3	-	23.8	15	7.83	13
02	AU	"	130	5	.07	18.5	2×10^0	8	"	-	8.15	"
03	BU	"	-	-	-	-	230×10^3	-	"	15	7.83	"
04	AU	"	130	5	.07	18.5	0	8	"	-	8.15	"
05	BU	"	-	-	-	-	400×10^3	-	"	15	7.83	"
06	AU	"	130	5	.07	18.5	5×10^0	8	"	-	8.15	"
07	BU	"	-	-	-	-	1720×10^2	-	"	15	7.83	"
08	AU	"	130	5	.07	18.5	0	9	"	-	8.15	"
09	BU	"	-	-	-	-	1300×10^2	-	"	15	7.83	"
10	AU	"	130	5	.06	15.8	17×10^0	10	"	-	8.15	13.5
11	BU	"	-	-	-	-	1300×10^2	-	"	15	7.83	"
12	AU	"	130	5	.055	14.5	2×10^0	12	"	-	8.15	"
13	BU	"	-	-	-	-	790×10^3	-	"	15	7.83	"
14	AU	"	130	5	.05	13.2	5×10^0	12	"	-	8.15	"
15	BU	"	-	-	-	-	1720×10^2	-	"	15	7.83	"
16	AU	"	130	5	.05	13.2	5×10^0	12	"	-	8.15	"

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA	I_1 UW/CM^2	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. MG/L	BOD_5 MG/L	pH	TEMP. °C
42017	BU	28	-	-	-	-	230×10^3	-	23.8	15	7.83	13.5
18	AU	"	130	5	.05	13.2	5×10^0	13	"	-	8.15	"
19	BU	"	-	-	-	-	490×10^3	-	"	15	7.83	14
20	AU	"	130	5	.05	13.2	17×10^0	13	"	-	8.15	"
21	BU	"	-	-	-	-	1300×10^2	-	"	15	7.83	"
22	AU	"	130	5	.05	13.2	13×10^0	13	"	-	8.15	"
23	BU	"	-	-	-	-	230×10^3	-	"	15	7.83	"
24	AU	"	130	5	.049	12.9	8×10^0	13	"	-	8.15	"

APPENDIX D

DYNAMIC TEST DATA - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT

NO.	LOCATION	FLOW GPM	EXP. TIME SEC.	SENSOR NO.	I_1 UA.[1]	I_1 UW/CM^2[2]	COLIFORM MPN INDEX/100 ml.	TURB. JTU	AMM. NIT. UA/L	BOD_5 UA/L	pH	TEMP. °C
	AU											
72101	No. UV	28.0	-	-	-	-	490×10^3	3	3.2	11	7.25	26.5
02	"	"	-	-	-	-	490×10^3	3	"	"	"	"
03	"	"	-	-	-	-	1720×10^3	3	"	"	"	"
04	"	"	-	-	-	-	490×10^3	3	"	"	"	"
05	AU	"	130	1	.46	56.1	130×10^3	3	2.8	-	7.35	"
06	"	"	"	"	.38	46.4	79×10^0	3	"	-	"	"
07	"	"	"	"	.35	42.7	49×10^0	3	"	-	"	"
08	"	"	"	"	.34	41.5	49×10^0	3	"	-	"	"
09	"	"	"	"	.37	45.1	2×10^0	3	"	-	"	"
10	"	"	"	"	.36	43.9	0	3	"	-	"	27
11	"	"	"	"	.36	43.9	8×10^0	3	"	-	"	"
12	"	"	"	"	.36	43.9	33×10^0	3	"	-	"	"
92301	BU	28.0	-	-	-	-	2780×10^2	-	11.5	61	7.41	22
02	AU	"	130	1	.08	9.8	490×10^0	17	13.0	-	7.55	"
03		"	"	"	.095	11.6	49×10^0	18	"	-	"	"
04		"	"	"	.09	11.0	310×10^0	19	"	-	"	"
05		"	"	"	.095	11.6	130×10^0	17	"	-	"	"
06	BU	"	-	-	-	-	330×10^4	-	11.5	61	7.41	"
07	AU	"	130	1	.10	12.2	109×10^0	14	13.0	-	7.55	"
08		"	"	"	.07	8.5	330×10^0	23	"	-	"	"
09		"	"	"	.10	12.2	130×10^0	14	"	-	"	22.5
10		"	"	"	.08	9.8	330×10^0	16	"	-	"	"
11	BU	"	-	-	-	-	330×10^4	-	13.5	61	7.45	23
12	AU	"	130	1	.11	13.4	79×10^0	14	14.2			"
13		"	"	"	.10	12.2	210×10^0	13	"			"

APPENDIX E

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT AT DIFFERENT pH VALUES

March 16, 1970

	#1	#2
Turbidity JTU	8	8
pH	7.5	6.0
Temperature ^{o}C	11	11.5
Ammonia Nitrogen mg/l	5.6	5.3
Total Iron mg/l	.52	.52
BOD_5	9	-

Ultraviolet Intensity measured with
Probe 4 C.F. = 147
Trough I I_o ua = .47
Trough 1 I_1^o ua = .08
Trough 2 I_2^1 ua = .08
Depth - inches = 2.81

Absorption Coefficient

$$e^{-kd} = I/I_o$$

$$e^{-kd} = .08/.47$$

$$k = .62/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = .08/.1702$$

$$I_o = .47 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iav = I_o\left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = .47\ \left(\frac{1 - .1702}{1.75}\right)$$

$$Iav = .223$$

Average absolute dose
Iav x C.F.
.223 x 147
33 uw/cm^2

Calculated relative dose for exposure period.

33 uw/cm^2 x 50 sec. = 1650 $uw/sec/cm^2$
" x100 " = 3300 "
" x150 " = 4950 "

APPENDIX E

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT AT DIFFERENT pH VALUES

March 16, 1970

	EXPOSURE TIME SEC.	COLIFORM MPN INDEX PER 100 ml.	GEOMETRIC MEAN OF COLIFORM INDEX	SURVIVAL RATIO N/No
1 pH	7.50			
	0	33×10^3	51×10^3	
	0	79×10^3		
	50	17.2×10^2	13.7×10^2	2.68×10^{-2}
	50	10.9×10^2		
	100	49×10^0	4×10^1	7.83×10^{-4}
	100	33×10^0		
	150	33×10^0	2×10^1	3.92×10^{-4}
	150	11×10^0		
2 pH	6.0 Aliquot of above sample. pH lowered with buffer tablets.			
	0	46×10^3	27.97×10^3	
	0	17×10^3		
	50	10.9×10^2	7.31×10^2	2.61×10^{-2}
	50	4.9×10^2		
	100	10.9×10^1	7.3×10^1	2.61×10^{-3}
	100	4.9×10^1		
	150	13×10^0	1.7×10^1	6.08×10^{-4}
	150	23×10^0		

APPENDIX E

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT AT DIFFERENT pH VALUES

March 16, 1970

	#3	#4
Turbidity JTU	7	7
pH	5.95	7.39
Temperature ^{o}C	9.5	9.5
Ammonia Nitrogen mg/l	14.3	14.3
Total Iron mg/l	0.60	0.55
BOD_5	-	12

Ultraviolet Intensity measured with
Probe 4 C.F. = 147
Trough I I_o ua = .46
Trough 1 I_1 ua = .07
Trough 2 I_1 ua = .075
Depth inches = 2.81

Absorption Coefficient

$$e^{-kd} = I/I_o$$

$$e^{-kd} = .07/.46$$

$$k = .67/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I/e^{-kd}$$

$$I_o = .075/.1522$$

$$I_o = .49 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iav = I_o\left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = .49\left(\frac{1 - .1522}{1.88}\right)$$

$$Iav = .221 \text{ ua}$$

Average absolute dose
Iav x C.F.
.221 x 147
32 uw/cm^2

Calculated relative dose for exposure period.

32 uw/cm^2 x 50 sec = 1600 $uw/sec/cm^2$
" x100 " = 3200 "
" x150 " = 4600 "

APPENDIX E

STATIC TEST - ULTRAVIOLET IRRADIATION OF SEWAGE EFFLUENT AT DIFFREENT pH VALUES

March 16, 1970

#	EXPOSURE TIME SEC.	COLIFORM MPN INDEX PER 100 ml.	GEOMETRIC MEAN OF COLIFORM INDEX	SURVIVAL RATIO N/No
3 pH	5.95 Aliquot of sample. pH lowered with buffer tablet			
	0	17.2×10^4	11.66×10^4	
	0	7.9×10^4		
	50	7.9×10^2	8.62×10^2	7.39×10^{-3}
	50	9.4×10^2		
	100	17×10^0	11×10^0	9.44×10^{-5}
	100	7×10^0		
	150	5×10^0	7×10^0	6.01×10^{-5}
	150	11×10^0		
4 ph	7.39			
	0	13×10^4	13.54×10^4	
	0	14.1×10^4		
	50	4.9×10^2	2.89×10^2	2.13×10^{-3}
	50	1.7×10^2		
	100	8×10^0	9×10^0	6.65×10^{-5}
	100	11×10^0		
	150	11×10^0	7×10^0	5.17×10^{-5}
	150	5×10^0		

APPENDIX F

ULTRAVIOLET IRRADIATION OF F_2 PHAGE IN SEWAGE UNDER STATIC CONDITIONS

November 5, 1969

Turbidity JTU	9
pH	7.48
Temperature ^{o}C	18
Ammonia Nitrogen mg/l	0
Total Iron mg/l	0.31

Ultraviolet Intensity measured with
Probe 4 C.F. = 147
Trough 1 I_o ua = 1.27
Trough 1 I_1^o ua = .09
Trough 2 I_1 ua = .15
Depth Inches = 2.81

Absorption Coefficient

$$e^{-kd} = I/I_o$$

$$e^{-kd} = .09/1.27$$

$$k = .92/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = .15/.0709$$

$$I_o = 0.12 \text{ ua}$$

Calculated average intensity in Trough 2

$$Iav = I_o \left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = 2.12 \left(\frac{1 - .0709}{2.6}\right)$$

$$Iav = .76 \text{ ua}$$

Average absolute dose
Iav x C.F.
.76 x 147
111 uw/cm^2

Calculated relative dose for exposure period

111 uw/cm^2	x 40 sec	= 4440	$uw/sec/cm^2$
"	x 80 "	= 8880	"
"	x120 "	=13320	"
"	x160 "	=17760	"

APPENDIX F

ULTRAVIOLET IRRADIATION OF F_2 PHAGE IN SEWAGE
UNDER STATIC CONDITIONS

November 12, 1969

Turbidity JTU	10
pH	7.25
Temperature ^{o}C	17
Ammonia Nitrogen mg/l	0
Total Iron mg/l	0.36

Ultraviolet intensity measured with
Probe 4 C.F. = 147
Trough 1 I_o ua = 1.0
Trough 1 I_1 ua = .07
Trough 2 I_1 ua = .10
Depth Inches = 2.81

Absorption Coefficient

$$e^{-kd} = I_1/I_o$$

$$e^{-kd} = .07/1.0$$

$$k = .92/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = .10/.07$$

$$I_o = 1.43 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iav = I_o\left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = 1.43\left(\frac{1 - .07}{2.6}\right)$$

$$Iav = .511 \text{ ua}$$

Average absolute dose
Iav x C.F.
.511 x 147
75 uw/cm^2

Calculated relative dose for exposure period

75 uw/cm^2 x 40 sec. = 3000 uw/sec/cm^2
" x 80 " = 6000 "
" x120 " = 9000 "
" x160 " =12000 "

APPENDIX F

ULTRAVIOLET IRRADIATION OF F_2 PHAGE IN SEWAGE UNDER STATIC CONDITIONS

November 25, 1969

Turbidity JTU	6
pH	7.19
Temperature ^{o}C	14
Ammonia Nitrogen mg/l	0
Total Iron mg/l	0.33

Ultraviolet Intensity measured with

Probe 4 C.F = 147

Trough 1 I_o ua = 1.35

Trough 1 I_1 ua = .08

Trough 2 I_1 ua = .13

Depth Inches = 2.81

Absorption Coefficient

$$e^{-kd} = I_1/I_o$$

$$e^{-kd} = .08/1.35$$

$$k = .996/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = .13/.0593$$

$$I_o = 2.19 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iav = I_o\left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = 2.19\left(\frac{1 - .0593}{2.8}\right)$$

$$Iav = .736 \text{ ua}$$

Average absolute dose

Iav x C.F.

.736 x 147

108 uw/cm^2

Calculated relative dose for exposure period.

108 uw/cm^2 x 40 sec. = 4320 $uw/sec/cm^2$

" x 80 " = 8640 "

" x120 " =12960 "

" x160 " =17280 "

APPENDIX F

ULTRAVIOLET IRRADIATION OF F_2 PHAGE IN SEWAGE UNDER STATIC CONDITIONS

December 4, 1969

Turbidity JTU	3
pH	7.35
Temperature ^{o}C	9
Ammonia Nitrogen mg/l	0
Total Iron mg/l	0.31

Ultraviolet Intensity Measured With

Probe 4	C.F.	= 147
Trough 1	I_o ua	= 1.15
Trough 1	I_1 ua	= .085
Trough 2	I_2 ua	= .14
Depth Inches		= 2.81

Absorption Coefficient

$$e^{-kd} = I_1/I_o$$

$$e^{-kd} = .085/1.15$$

$$k = .92/\text{inch}$$

Calculated I_o in Trough 2 where exposure was made

$$I_o = I_1/e^{-kd}$$

$$I_o = .14/.0739$$

$$I_o = 1.89 \text{ ua}$$

Calculated average intensity in Trough 2.

$$Iav = I_o\left(\frac{1 - e^{-kd}}{kd}\right)$$

$$Iav = 1.89\ \left(\frac{1 - .0739}{2.6}\right)$$

$$Iav = .673 \text{ ua}$$

Average absolute dose

Iav x C.F.

.673 x 147

99 uw/cm^2

Calculated relative dose for exposure period

99 uw/cm^2	x 40 sec.	= 3960	$uw/sec/cm^2$
"	x 80 "	= 7920	"
"	x120 "	=11880	"
"	x160 "	=15840	"

APPENDIX F

PLAQUE COUNTS FOR STATIC PHAGE TESTS

EXPOSURE TIME SECONDS	P.F.U.	SURVIVAL RATIO N/No
1. November 5, 1969		
0	1×10^{7}	-
40	2.34×10^{6}	2.3×10^{-1}
80	3.20×10^{5}	3.2×10^{-2}
120	5.40×10^{4}	5.4×10^{-3}
160	1.14×10^{4}	1.1×10^{-3}
2. November 12, 1969		
0	1.63×10^{5}	-
40	8.55×10^{3}	5.2×10^{-2}
80	1.03×10^{3}	6.3×10^{-3}
120	1.05×10^{2}	6.4×10^{-4}
160	1.00×10^{1}	6.1×10^{-5}
3. November 25, 1969		
0	8.90×10^{4}	-
40	2.42×10^{4}	2.7×10^{-1}
80	2.19×10^{3}	2.5×10^{-2}
120	3.35×10^{2}	3.8×10^{-3}
160	4×10^{1}	4.5×10^{-4}
4. December 4, 1969		
0	1.44×10^{5}	-
40	3.45×10^{4}	2.4×10^{-1}
80	5.45×10^{3}	3.8×10^{-2}
120	1.01×10^{3}	7.0×10^{-3}
160	1.50×10^{2}	1.0×10^{-3}